VOL. XV, NO. 4, JULY 1970

OCEANUS

ON THE COVER—

MAGNIFIED 7,500 TIMES—D. BUKRY

Coccoliths

The shape on our cover is the plate of a group of minuscule golden brown algae, called coccolithophorids. Magnified about 58,000 times, they can be studied in detail only with the aid of an electron microscope.

Coccoliths make up the bulk of the "White Cliffs of Dover" and were found in extremely thin "chalky" layers in Black Sea sediments, which were determined to exist almost entirely of one species: *Emiliania huxleyi.*

During a bloom of these plants, a liter of surface water may look milky and contain up to one million cells of these algae.

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Jan Hahn, *Editor*

OCEANUS™

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THE WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

Editorial

FOR many years we felt a lack in the coverage of Oceanus in that we rarely seemed to have articles on the geochemistry of the sea. This issue, devoted to the cruise in the Black Sea made by the R.V. 'Atlantis II' in April and May 1969, covers quite a bit of ground, literally and figuratively. Some of the fare is a bit heavier going than our readers usually enjoy. Still—this is an important aspect of modern oceanography which, after all, has become more and more complex.

Not the least important aspect of the Black Sea cruise was the international cooperation and the opportunity to exchange ideas with Russian oceanographers. Scientists from many nations took part in the work at sea on various legs of the cruise. The ship visited two Russian ports and we cannot think of a better way to "show the flag" than having a modern, extensively equipped research vessel do so.

Russian visitors examining Black Sea bottom records on board the R.V. 'Atlantis II'

KARADENİZ

Черно море

ЧЕРНОЕ МОРЕ

MAREA NEAGRĂ

'Atlantis II' Cruise #49 to the Black Sea

THE Black Sea is one of the more unusual bodies of water in the world. Marine life, as we generally know it, can exist only in the upper 200 meters. Below that depth there is no oxygen present, so that only certain bacteria which need no oxygen can survive.

Rainfall and run-off from rivers and land drainage exceed evaporation, causing a surface layer of water of relatively low salinity and corresponding low density. The accumulation of fresh water, together with temperature conditions in the upper layers of the Black Sea, also prevent aeration of the deeper water through convection currents. The only way in which the deeper water could be renewed under these circumstances is through inflow of oxygenated deep water from the outside. However, the Bosporus Ridge, which rises to some 40 meters from the sea surface, prevents the entrance of Mediterranean water.

The deep water in the Black Sea is practically stagnant; below 200 meters the oxygen has disappeared, instead large quantities of hydrogen sulfide (the smell of rotten eggs) are present. This is caused by the decomposition of rich organic material which has drifted down from the productive surface layers and, in decomposing, has used up all the free oxygen. From the bottom up, the toxic water extends upwards for about 1800 meters, while the stagnant part has about five times the volume of the upper portion where other forms of marine life are present.

Similar conditions exist in some Norwegian fjords, although not necessarily on a year round basis. In the open sea, as far as we know, there is only one stagnant basin, the Cariaco Trench off the coast of Venezuela. The anearobic conditions in that trench were discovered in December 1954 by Mr. L. V. Worthington of our staff. Chemical and geological investigations in the trench were carried out later from the R.V. 'Atlantis' by Drs. F. A. Richards and J. M. Zeigler then on our staff.*

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*See: The Cariaco Trench," by F. A. Richards, Oceanus, Vol. III, No. 3, Spring 1955.

On 'Atlantis II' Cruise #49

to the

Black Sea

by J. M. HUNT

It all started in the fall of 1968 when we received a grant from the National Science Foundation (N.S.F.) to return to the Red Sea following our successful studies there in 1966. When it became apparent that the Suez Canal would remain closed, we received permission from N.S.F. to change the area of study to the Black Sea. Many of our scientists long had wanted to enter the Black Sea but there were political as well as scientific problems involved in the logistics of this kind of a cruise. Fortunately, in January, 1969, two distinguished Russian oceanographers visited the Boston-Woods Hole area to lecture and attend a meeting of the Intergovernmental Oceanographic Commission of UNESCO. These were Professor Monin, Head of Oceanography at the Academy of Sciences of the U.S.S.R. and Admiral Rassokho, Chief of the Hydrographic Office at Leningrad. Both of these gentlemen were receptive to our proposed study of the Black Sea especially when we offered to accommodate some Russian oceanographers on the cruise.

We planned a multi-disciplinary cruise involving all aspects of oceanography with personnel from several universities both in the U.S. and abroad. We included invitations to scientists of all the border countries, Turkey, Bulgaria, Rumania, and the U.S.S.R. Also, the suggestion was made to the Soviets that the R/V 'Atlantis II' stop at two Russian ports, preferably Novorossiysk and Sevastopol in order to exchange visits with Russian oceanographers and to take some of them on a short cruise.

As the ship left Naples we had foreign scientists on board from Kiel, Heidelberg, Göttingen, Gøteborg, Ismir, and Trieste. As the ship passed through the Bosporus, we picked up two Turkish scientists, one from the Hydrographic Office in Istanbul and the other from the Minerals Research Institute in Ankara.

During the first three weeks in the Black Sea, it was obvious that the Russians were not quite convinced of our character. The shadowing and photographing of our ship by airplanes and ships plus monitoring of all communications was fairly continuous even though the weather was cold and stormy with a cloud cover most of the time. The ships always remained a respectable distance behind us especially when we were towing gear. At all times, we stayed beyond the 200 meter contour or fifteen miles offshore to avoid any diplomatic problems.

Despite the cold and stormy weather, about thirty stations were made including a cluster off the mouth of the Bosporus. We were lucky in having most of the equipment in good working order so that a large amount of geophysical and heat flow data were obtained along with a large number of sediment cores and water samples. Among the more sophisticated equipment on board was a six-channel automatic chemical analyzer for determining most of the important chemical parameters in the sea water.

Istanbul

The first leg terminated in Istanbul on April 7 where we were greeted by Commander Özturgut, Chief of the Hydrographic Office of the Turkish navy and his Aides. We were berthed at a fine dock positioned almost in the center of the city. The next day we invited the press and government officials and educators to visit our ship. The Turks were greatly impressed and we received most favorable reports in six of the seven Turkish newspapers. Also, through the U.S. embassy office we arranged a cocktail party on board for the benefit of representatives of foreign governments in Istanbul. We had representatives of the Embassies of Rumania, Bulgaria, U.S.S.R., England, and West Germany, plus those from several other eastern and central European countries. It was a fine friendly party and it was particularly interesting how readily the representatives of the capitalist and communist countries got along together.

The next day we got into a motor launch for a ride up the Bosporus to the Hydrographic Office of the Turkish Navy. Commander Özturgut proved to be a charming host who had spent some time in America and had obtained a degree from the University of Michigan. We were given a detailed report in English from several of the Turkish scientists regarding their work in the Black Sea. It was most interesting that their research covered only the southern two-thirds of the sea. They had orders not to penetrate the area to the north even though they were well outside the territorial limits of Russia.

No Life

On April 11 we headed north for the second leg on what later proved to be the most adventurous part of our cruise. During this leg the sun came out, the sea became relatively calm, and surface temperatures warmed up from about 5° to about 9°C. Our Russian shadowers disappeared during this leg except for one jet and one ship that came out to greet us when we were stationed off the main Soviet submarine port of Batumi. Our track during the second leg covered stations 1461 through 1487. Most of these were in the eastern half of the Black Sea. During most of this cruise few vessels of any kind were sighted. Apparently, most of the traffic in the Black Sea is in the western half where the population in coastal areas is much higher. The eastern half had almost no shipping, and fishing vessels are confined to the coastal areas which contain most of the marine life. There is no deep-sea fishing in the Black Sea since the water contains poisonous hydrogen sulfide at depths greater than about 100 meters. The interface between the oxygenated surface waters and the hydrogen sulfide waters is actually concave with a depth as low as 75 meters near the center of the Black Sea and up to 250 meters along the edges. During most of this second leg we saw no sign of life in the Black Sea except an occasional dolphin.

On April 4, as the 'Atlantis II' made her way along the southeast coast of the U.S.S.R., word was received that the ship could enter the Russian ports of Novoros-

On the bridge of the 'Atlantis II', Captain E. R. Hiller and Dr. J. M. Hunt check a chart showing the ship's track and stations in the Black Sea. Seaman A. Sture is on the wheel.

With the snow capped Caucasus mountains in the background, a box corer is hauled back on deck. This corer opens up to reveal a square core of sediment. It was designed and built in Kiel, Germany.

siysk and Yalta, where we could visit with Russian scientists.

Russian Ports

It was a cloudy, foggy day when we steamed up the long channel leading into Novorossiysk. We were the first American ship to enter the port since World War II and the first foreign oceanographic vessel ever to visit. As we passed some of the freighters lined up along the docks we exchanged waves and smiles with the crews who consisted of a mixture of men and women.

While Captain Hiller was dealing with the port authorities, I welcomed Dr. Ovchinnikov, Director of the Gelendzhik Laboratory and his assistants into my cabin. Dr. Ovchinnikov said that he wanted to take all of our scientists by motor launch to Gelendzhik, a small town about ten miles southeast from Novorossiysk. All of the scientists were anxious to go, so after completing our negotiations with the authorities, we all boarded the motor launch.

We were led to what appeared to be an old estate, probably of some former wealthy Russian. The Gelendzhik Laboratory is actually a collection of buildings called the Southern Branch of the Institute of Oceanography of the Academy of Science, U.S.S.R. At the main building the American flag was hanging alongside the Russian flag to welcome us. Inside, the rooms reminded me of my first visit to Soviet laboratories in Moscow in 1962. There were the usual dark red rugs, heavy drapes over the windows, and plaster walls. After several welcoming speeches and a reply by our people, we all sat down to long tables heavily laden with food and drink. The Russians always serve vodka, cognac, and wine and a few bottles of warm fruit drinks for teetotalers. Caviar, cheese, fish, and meat plus the good dark Russian bread are the main food staples. After exchanging several toasts and gorging ourselves on the food, we divided into groups. The Russians provided scientists with some knowledge of English to each group. They were quite generous in show-

The Russian version of a Sealab was undergoing pressure tests while our scientific party was visiting the Gelendzhik Laboratory near Novorossiysk.

Analyzing seawater for nutrients has been a tedious and time consuming operation. A prototype model of a new AutoAnalyzer provided intricate chemical analyses without danger of contamination. The rotating sample table is being shown to visiting Russian scientists by Dr. K. Grasshof, whose work during the cruise aided in developing the production models.

ing us everything they were doing and letting us take pictures of their equipment and data sheets. In addition they gave us a large number of their publications, books as well as reprints. They apparently were doing considerable research in the Mediterranean and except for biology had not studied the Black Sea in great detail. The scientists were enthusiastic and particularly happy at the opportunity to discuss their work. However, it was quite obvious to most of us that the laboratories were poorly equipped. The state of their analytical chemistry seemed to be that of western institutions about twenty years ago. They were forced to work with relatively simple instruments rather than the highly sophisticated equipment that is so common in the U.S. The pattern fit that of my previous visits to the U.S.S.R. in that the major centers of science and education in Moscow and Leningrad receive the best equipment with the small isolated laboratories obtaining practically nothing. The Gelendzhik scientists seemed to be somewhat out of touch with recent western developments and even in poor cooperation with their own scientists at other laboratories such as Sevastopol. The people seemed to be eager enough. It was more a matter of inadequate funds for both travel and equipment.

Visit & Visitors

During our stay at Novorossiysk, both scientists and the crew were given complete freedom to visit the city and surrounding areas although we were asked not to photograph port stations, railways, and bridges. The local seamen's club arranged some tours but generally we wandered around the city on our own in small groups taking pictures and buying things at the local stores. At no time was there evidence that we were being followed.

We left Novorossiysk early on April 29 with three Russian scientists including Dr. Ovchinnikov. During the next few days we made several stations in the Black Sea at which the Russians were able to observe all of our operations. Only one of them could speak English so he generally acted as interpreter. The scope of our equipment apparently overwhelmed them because they seemed to make notes about everything.

As we approached Yalta on May 1, most of the city was enveloped in fog but we could make out a large number of banners proclaiming the May Day celebrations. In Yalta we were advised by the Russians that it would not be possible to visit the oceanographic laboratories in Sevastopol because they were closed for

the festivities which would last several days. Several scientists from the Sevastopol laboratories, however, planned to visit us on May 2nd. We were not surprised about the Sevastopol visit because this city has been closed to foreigners for years. The following morning about fifteen scientists visited our ship from the Institute of Biology of the Southern Seas including the Director, Dr. G. G. Polikarpov. Another ten scientists headed by Dr. Metalnikov came from the Marine Hydrophysical Institute of the Academy of Science of the Ukraine in Sevastopol.

In our first discussions with the Sevastopol scientists it became apparent that they were considerably more competent scientifically than our friends in Gelendzhik. They had a good knowledge of recent western literature and they showed great interest in our most sophisticated instrumentation. We made several good contacts during these discussions and they were generous in giving us a large number of their books and reprints. They have done considerable work in both the Mediterranean and the Black Sea. Sevastopol is somewhat like Woods Hole in that it has several marine research organizations with a long history of distinguished work. Dr. Polikarpov was genuinely unhappy that we could not visit his laboratory and he hoped that this could be arranged in the future.

Luxury Liners

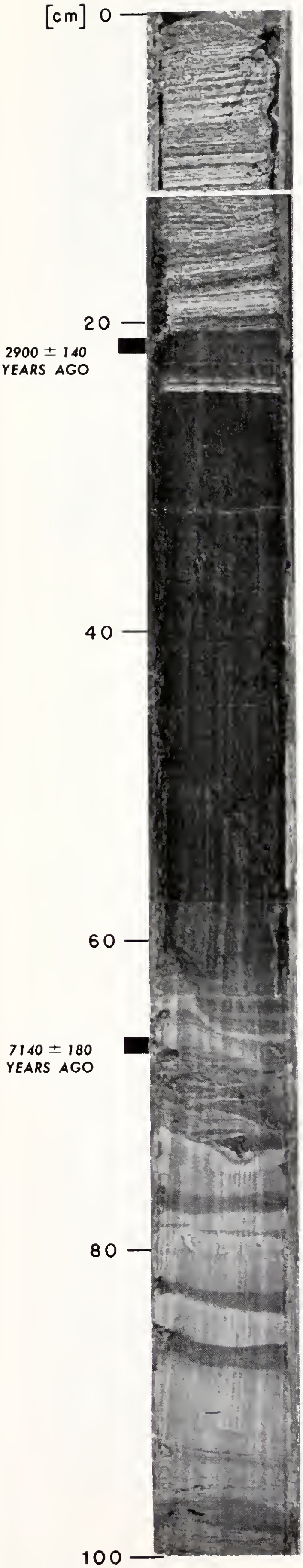
On May 3 the scientists and crew had an enjoyable time visiting with Russians in Yalta both in their homes and places of business. Yalta is without doubt one of the freest places I have ever visited in the Soviet Union possibly due to the fact that it is a resort city. We were allowed to photograph anything in the city and participated in many of the holiday celebrations. We visited with the crew and passengers of two large luxury liners which were berthed next to our ship. Both of these liners were built in East Germany and were beautifully furnished including a large music room and swimming pool. The ships carry a heavy tourist trade between Odessa, Yalta, and Istanbul. There were also several hydrofoils in port most of which were built in Italian ship yards. Four of us went for a ride on a twenty-passenger hydrofoil and soon after boarding were practically flying through the water at a speed of about forty-five knots. The ship handled beautifully except every so often it would skim over a trough and hit the following wave so hard that it would shake the whole ship. We travelled about ten miles up the coast north of Yalta taking pictures all the way.

Pleasant Visit

The main square in Yalta had large portraits of some of the Russian leaders but most of the people seemed more interested in having a good time than listening to the political speeches. The big dinner/dance hall in Yalta was crowded every night with the band playing western music almost constantly. Most services are at a premium. Restaurants for example are so crowded every evening that you need to know someone in order to get a table. However, there are many outdoor eating places and the whole atmosphere is reminiscent of the New Jersey seacoast in summer. In fact, the main walk along the Yalta coast, which is crowded with Russians from morning to night, is reminiscent of the Atlantic City boardwalk.

Although we had soldiers guarding our ship at Yalta they were much more lenient than at Novorossiysk. We were supposed to be on the ship at midnight every night. Occasionally we didn't make it until early morning, but the soldier dutifully waited for us. As in Novorossiysk, it appeared that the guards were mainly there to prevent Russians from boarding our ship rather than to prevent us from getting off.

Early on May 4 we departed from Yalta and made a straight run to Istanbul across a foggy Black Sea. Several scientists disembarked at Yalta so we put on Mr. & Mrs. Hauck, the U.S. Vice-Consul stationed at Istanbul. The cruise to Rhodes gave them a better understanding of the operations and problems on an oceanographic vessel. The cruise was completed in Rhodes on May 7. All in all it was a most successful event both from the scientific and the political point of view. We not only learned a great deal about the Black Sea but also made friends with many of the scientists in the countries surrounding the sea.



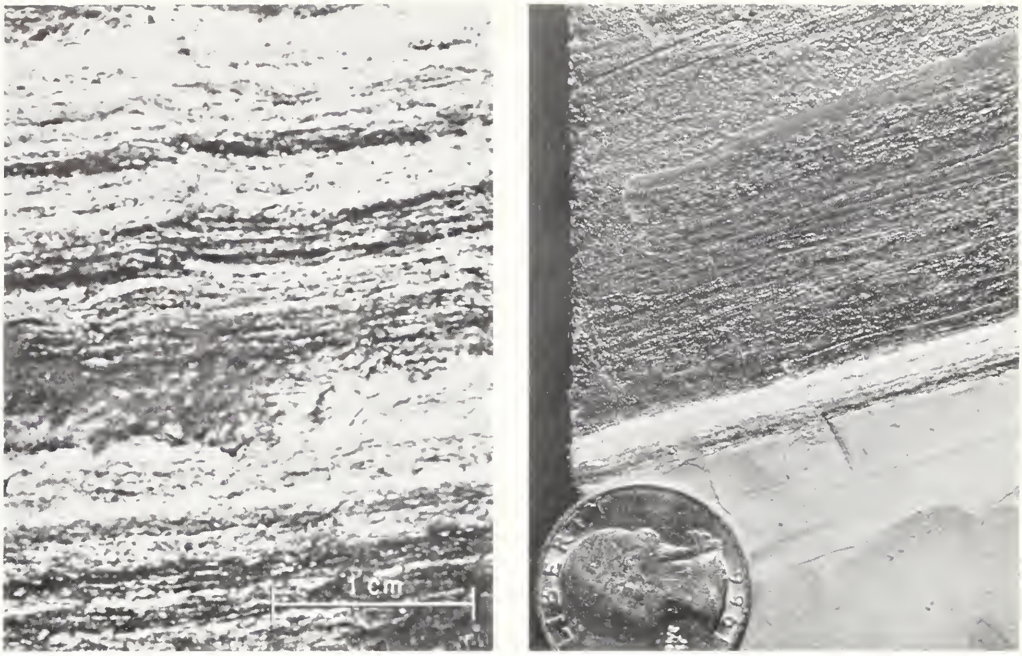
FROM METER TO CENTIMETER TO MICRON AND FINALLY TO ÅNGSTROM UNITS

by

E. T. DEGENS, S. W. WATSON and C. C. REMSEN, III

OCEAN bottom sediments record the history of our changing earth. They have recorded, over a wide span of time, all of the changes which have occurred in the geological environment. Morever, the evolution of organisms can be traced back in minute detail by carefully investigating the fossil record preserved in the sediments. In order to unravel the mysteries of both the geological and biological past, mysteries which are often hidden to the naked eye, scientists are using an impressive arsenal of sophisticated instruments including mass spectrometers, spectrographs, and x-ray devices. Another powerful tool is the electron microscope which can enlarge materials directly up to 500,000 times without loss of detail in form and structure.

To illustrate the use of electron microscopy to obtain information on the history of our earth, we have selected the top one-meter section of a 12 meter sediment core taken in the central part of the Black Sea at a water depth of 2,000 meters. On the basis of radiocarbon dating, the age of the sediment at the base of that top meter is almost 10,000 years. Relative to the age of the earth, which measures in billions of years, this time interval of 10,000 years does not sound too impressive. On the other hand, 10,000 years covers quite a bit of the history of man.



Fine layered structure of a 5 cm section is shown by successive photographic enlargements. The coin is a U.S. quarter. For our foreign readers, who do not have "two bits" handy, the diameter of the coin is about 23 mm.

The sediment profile has an extremely fine layered structure. Many of the details come to light only if the photograph is enlarged, as can be seen from the blowup of a 5 cm section taken from the upper 20 cm of the profile. Light and dark layers appear to alternate in a systematic fashion at the rate of approximately 50 per cm of section. Since the rate of deposition is on the order of 1 to 2 cm per hundred years, the observed relationships suggest an annual or semi-annual deposition cycle. This core section is not unique. Similar layers were found at most points of the Black Sea where cores were taken below a water depth of 2,000 meters. This would tend to suggest a history of uniform deposition in the Black Sea over the last 10,000 years.

Coccoliths

The above was clear from an examination by the naked eye and by photographic enlargement. The use of an optical microscope, which permits a thousand fold magnification, provided relatively little more information. Higher magnifications were required if the structure of individual particles within the sediments were to be resolved.

When samples from the light colored layers in the upper 20 cm of the sediment section were examined in the electron microscope, it was found that they were comprised almost entirely of coccoliths, consisting of a single species *Emiliania huxleyi*. These coccoliths are composed of calcite which is a mineral form of calcium carbonate ($CaCO_3$) and measure about 2 to 3 microns in diameter, one is shown on the cover of this issue. On the other hand, the black layers of the sediment appeared to consist entirely of cellular fragments and organic remains, well preserved and showing remarkable detail when examined with the electron microscope.

Chemical Analysis

Prior to the microscopic work, a chemical analysis of the sediment was made. Considerable variation in total phosphorus, organic carbon, organic nitrogen, and calcium carbonate were found within the sediment section. Organic carbon and nitrogen increase slowly to a depth of about 25 cm, at which point they rapidly increase reaching a maximum value of about 20 percent for organic carbon and 1.5 percent for nitrogen at 55 cm. These values then decrease abruptly reaching minimum values at about 75 cm. Samples for analysis were removed at intervals of 3 cm, and a 1 cm layer was homogenized to determine the chemistry. Since the alternating layers were as thin as one millimeter, it must be emphasized that our chemical analyses only reflect general

trends of calcium carbonate (coccoliths) and organic matter deposition, rather than a precise value at any given time because the layers are so thin that it is difficult to sample a single one without contamination.

On land, coal and peat deposits are well known but the presence of such high amounts of organic material in sediments of marine origin is unique. Therefore, emphasis was placed on an electron microscopic examination of those layers extending from 20 to 70 cm below the surface of the sea floor. Samples were treated in various ways. Some were examined directly while others were stained with a solution of a heavy metal to add contrast to the specimen. In certain instances, as in the case of some of the coccoliths, the high concentration of metals in the sediments resulted in a natural staining of the organic matrix responsible for the deposition of the shell, thereby revealing the growth pattern in the form of rings and bands similar to those observed in trees. Still other samples were stained with osmic acid, embedded in an epoxy plastic, and finally cut into an extremely thin section with a diamond knife.

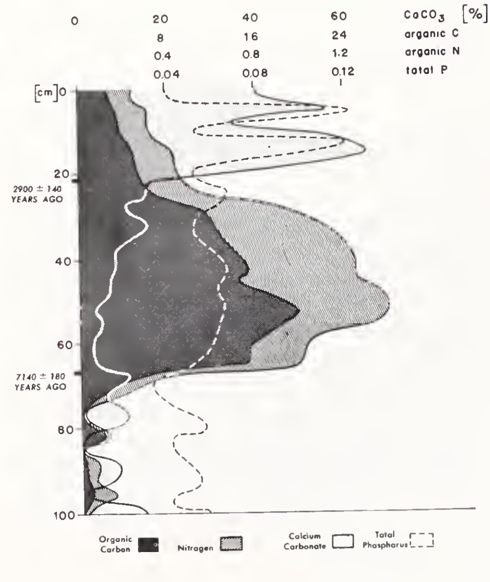
A coccolith showing natural staining due to high concentration of metals in the bottom sediment.

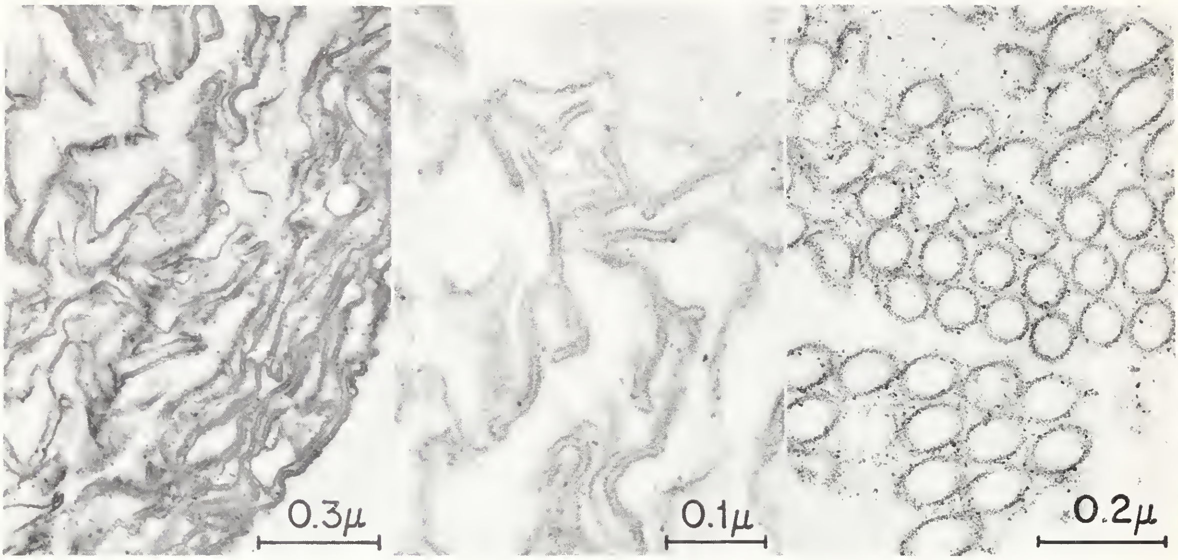
Membranes

Numerous structures resembling biological membranes were clearly visible in all of these preparations. This was particularly interesting to us, since membranes are not normally found this deep in marine sediments. Membranes play an important role in nature; they house the enzymes needed for energy production within a cell — thus they may be considered as the powerhouse, producing energy without which plant and animal cells would not survive. Therefore, any information that we might gain on the structure and formation of membranes in general will be of significant value.

The most prominent structures found in the sediments were membranes, usually in the form of sheets, and casually distributed throughout the section. Occasionally these sheets of membranes were aggregated, but since other parts of an organism were not present, it is impossible to speculate on the type of life from which these membranes originated. Other

The chemical analyses of the core section shown on page 11 reflect general trends of deposition, as explained in the text.





Tubular membranes of various dimensions

types of membranes seen were of a unique tubular and branching nature. Since membranes of this type are quite rare in present day forms of life, we were intrigued by their abundance in 3,000 to 7,000 year old sediments. Today, such membranes are found only in energy producing parts of the cells (called mitochondria) of higher organisms and in some bacteria.

Several Explanations

Several explanations for the occurrence of these membranes in the Black Sea sediments come to mind. In the first place, they may be remnants of some undescribed single-celled organisms, which have been preserved for several thousand years in the sediments of the Black Sea. The presence of large amounts of metals in the pore water of the sediments,* as well as the lack of dissolved oxygen, may account for their excellent preservation.

A second possibility is that the tubular membranes may have been derived from other kinds of membranes. We do know that changes in the structure of membranes occur in cells when there are fluctuations in the chemical content of body fluids. During the time period under consideration, such changes also did occur in the Black Sea environment. During the period between 3,000 and 7,000 years ago there was a gradual but fluctuating change in the Black Sea from fresh water to sea water. The resulting salinity gradient in the sediment promoted a natural separation of organic materials according to their chemical make-up. This is the same kind of separation process utilized by the analytical chemist for the isolation and identification of individual compounds in a mixture of organic materials, and is known as chromatography. This separation process stimulated structural changes in the membranes present in the sediment. Changes in the chemical environment also resulted in the dissolution or breakdown of existing organic material. This again was followed by a natural separation and concentration of organic fragments and finally a reaggregation of these components into a different structural form took place.

A third possiblity is that these membranes are of non-biological origin. Namely, proteins and phospholipids, which are the principal components of all membranes, were formed on minerals such as clays and carbonates. These minerals acted as a kind of copying machine in much the same way as nucleic acids are used in the synthesis of biological proteins.

Fragments

In addition to the membranes, fragments composed of structures resembling certain bacterial cell walls, were found in some of the sediment layers. Some of these fragments were spherical sac-like structures but most appeared tubular. These structures were 1 to 2 microns wide and 1 to 15 microns long with sharp angular ends giving them the appearance of crystals. At least four distinct arrangements were recognized. Many of these

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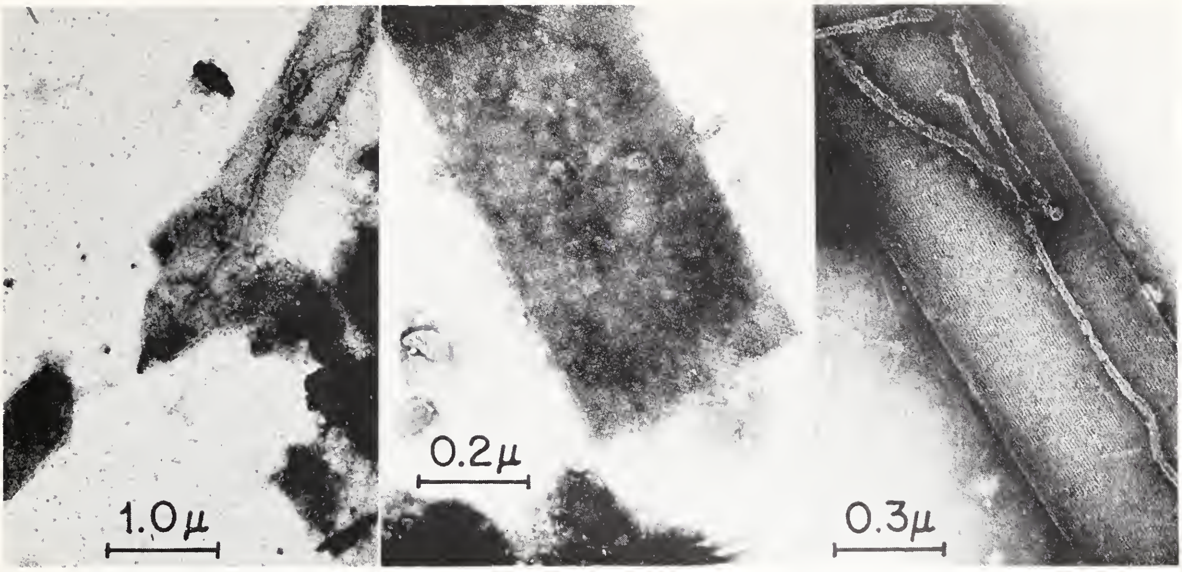
*See page 30



Bacterial cell walls or protein crystals?

fragments are partially intact bacterial cell walls but the possibility must be considered that these fragments were formed as a result of changes in the geological and biological environment which led to the breakdown and subsequent rebuilding of organic molecules. The last idea finds its strongest support in the wide range of sizes of the individual organic crystals and their occurrence in distinct layers within the sediment section under study. The same argument holds true also for the membranes which are often concentrated in layers.

Dormant Bacteria

Some bacteria have been cultured from these sediments. However, it should be noted that they existed in the sediments in a passive or resting stage rather than in an active stage. This is inferred from the presence of aerobic bacteria (requiring oxygen) in an anaerobic habitat (no free oxygen). These bacteria were derived from the oxygenated surface waters and became sedimented like the carbonates and clay minerals. This observation has interesting implications since it suggests that bacteria remain in a state of suspended animation for prolonged periods of time, perhaps thousands of years.

An interesting idea can be brought forward that sediments, such as those in the Black Sea, represent a gigantic cell where processes similar to those in biological cells are taking place. It is reasonable to assume that in the early dawn of earth, processes, sketchily described here, led to the formation of life. In this sense, such sediments are both the descendant as well as the mother of life.*

Little Definitions

METER is equal to 100 centimeters

CENTIMETER is equal to 10 millimeters

MICRON is equal to one-thousandth of a millimeter

ÅNGSTROM is equal to one ten-millionth of a millimeter

ANOXIC-ANAEROBIC: refer to conditions when no free oxygen is present

HYDROGEN-SULFIDE: poisonous gas — smells of rotten eggs

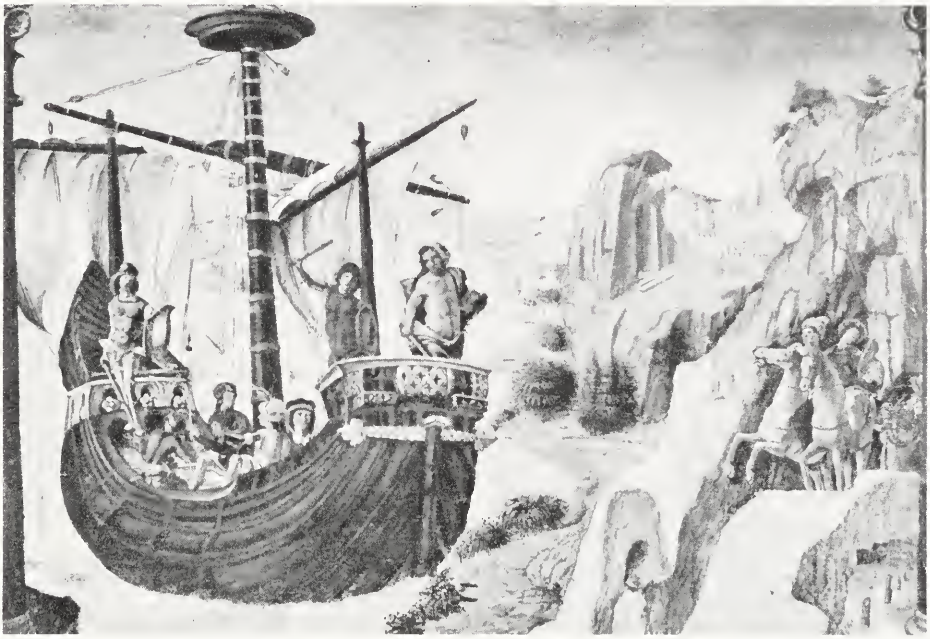
PORE WATER: water squeezed out of sediment core

kHz: kiloHerz, formerly kilocycle, one thousand cycles per second

*Structural Molecular Biology of Phosphates by J. Matheja and E. T. Degens. Fischer Verlag, Stuttgart, 1970.

In the harbor of Yalta, our R.V. 'Atlantis II' is overshadowed by a Soviet passenger ship.

Geophysical Studies In the Black Sea



JASON ON BOARD THE 'ARGO'

By D. A. ROSS, E. UCHUPI, C. O. BOWIN and K. E. PRADA

CERTAIN places, because of the magic of their names, have never ceased to feed the imagination of men. One of these places is the Black Sea, which received its name from the Turks who feared its stormy waters. Their epithet for the sea was the word Karadeniz or Black. However, to the ancients who plied their trade along its shores, the sea was known as Pontus Euxinus or Hospitable Sea. The Black Sea—connected to the Mediterranean by the narrow Bosporus and Hellespont, named after Helle, the daughter of Athamas who drowned there—has served as the stage for many of the most dramatic events in human history. From the steppes that border the northern coast of the Black Sea came the Achaeans, the first Greeks who migrated into the peninsula that bears their name. To the Black Sea came Jason and the mighty Argonauts aboard the 'Argo' in search of the Golden Fleece. Near the borders of the Black Sea the city of Troy was destroyed over 1000 years before the birth of Christ. Who can forget Homer's epic poem describing the wrath of Achilles, the bravery of Patroclus, the wisdom of Nestor, and the wilyness of Odysseus?

Many other events have also played their acts on the Black Sea stage; Xenophon and ten thousand men marching northward across the Persian Empire to reach the shores of the Black Sea; the foundation of Constantinople and its sacking, first by the Crusaders and later by the Ottoman Turks; the charge of the Light Brigade near Sevastopol during the Crimean War; the Gallipoli expedition during World War I; and the heroic stands of the Russians during World War II.

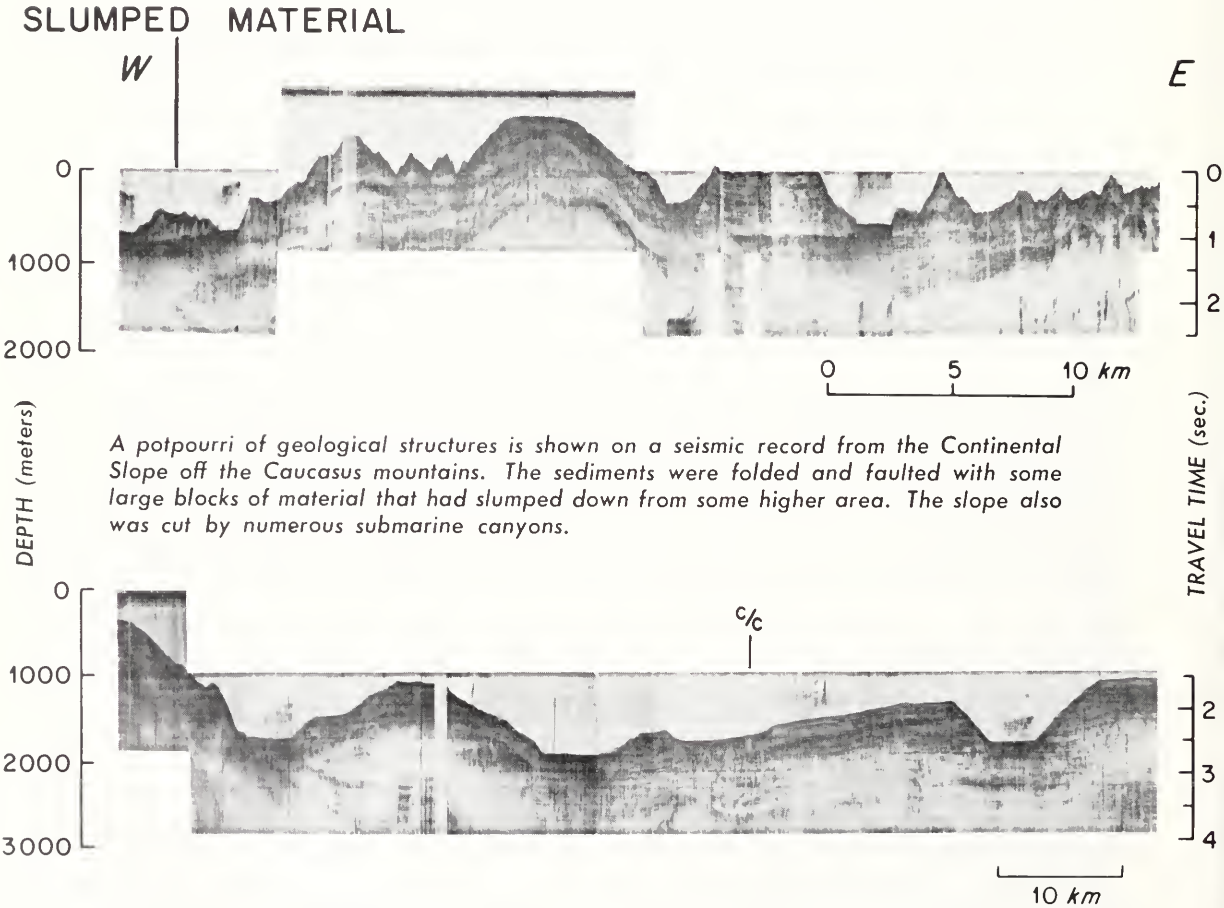
Over three thousand years after the 'Argo' sailed into the Black Sea in search of the Golden Fleece, our vessel entered the Black Sea. The cruise of the 'Atlantis II' may have not been as dramatic as the task imposed on Jason, but much was learned about the natural history of this nearly landlocked sea.

Russian scientists have long known that the crustal structure of the Black Sea is different from typical oceanic or continental areas. Under the ocean the earth's crust is about 7-8 km thick, much of which is basalt. Under the continents the crust is about 30 km in thickness; of which

at least the upper material is granite. The crust of the Black Sea is over 20 km thick but apparently does not have seismic velocities associated with granitic material. Thus it is intermediate between oceanic and continental crust and may represent a transition type of crust. Some scientists have suggested that the Black Sea is in the process of becoming oceanic; other scientists argue that it is becoming continental. We hoped during the 'Atlantis II' cruise to attempt to resolve this problem. In addition, we also wanted to learn something about the shallow structure by using a continuous seismic profiling system (CSP).*

Gravity Measurements

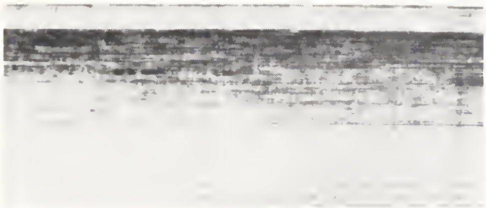
Gravity measurements were also made continuously during the expedition. Preliminary analysis of the data shows some low gravity zones near parts of the coasts of Turkey and Russia. These zones parallel trends of deformed areas occurring on land and may indicate that crustal movement is beginning in these areas. If these movements occur, the Black Sea eventually may become a large, folded mountain range. We should know more about this possibility in a few million years.



A potpourri of geological structures is shown on a seismic record from the Continental Slope off the Caucasus mountains. The sediments were folded and faulted with some large blocks of material that had slumped down from some higher area. The slope also was cut by numerous submarine canyons.

A record off the Turkish slope showed gentler folding and several large channels. The submarine canyons and channels probably are related to rivers on the mainland and may represent marine extensions of these rivers that were cut when sea level was lower.

*See: Oceanus, Vol. VII, No. 1, September 1960. "New Instrument & Methods."



Profiles from the deeper areas of the Black Sea—the abyssal plain—generally showed a much more subdued topography. In these areas, sedimentary layers (more accurately, layers which give an acoustical reflection) can be traced over much of the basin.

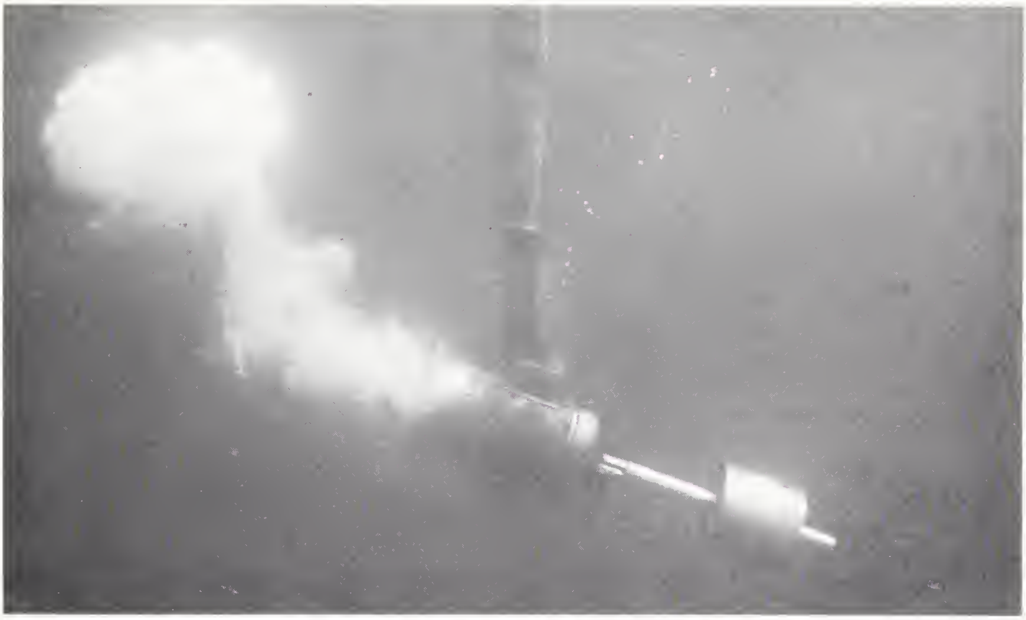
Many CSP records showed structures that suggest possible areas for oil traps. We showed some of these records to our Russian colleagues when we visited Novorosiysk and Yalta.

Sediment samples collected during the cruise allow us to distinguish the more recent history of the Black Sea. Apparently conditions found today have remained rather constant for some time. The deeper parts of the basin have been structurally quiet, resulting in large, thick layers of undisturbed sediment that can be correlated over large areas (see pages 26 & 27) whereas along the continental slope there has been faulting and folding. Cores taken from this area generally show indications of material distributed by turbidity currents and slumped material.

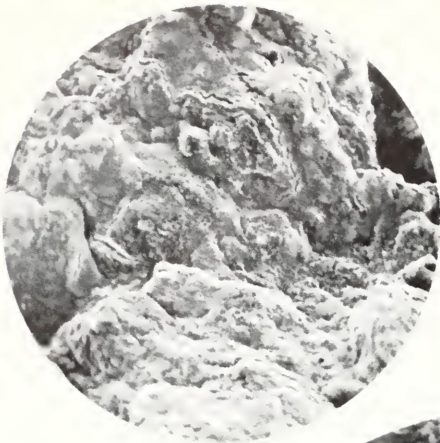
Up or Down?

The data collected during the cruise has been almost completely analyzed. In the near future this information, together with the knowledge of the geology of the surrounding regions will be used to reconstruct the geologic history of the Black Sea and hopefully answer certain questions such as: Was the Black Sea in the past a land mass that subsided to its present depth? Or is the Black Sea an ocean basin in the process of becoming a continent?

Has the size of the Black Sea fluctuated with time? What was the effect of the last ice ages on the sedimentary and hydrographic conditions of the sea? The quest of the scientists aboard the 'Atlantis II' may not have been as intriguing or as dangerous as the quest for the Golden Fleece, but in the long run, it may be more fruitful.

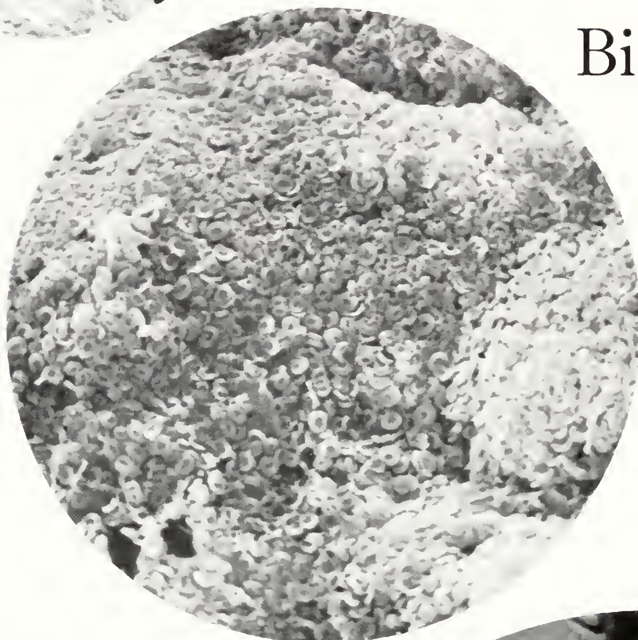


The burst of an air gun provides a loud report which penetrates the sedimentary layers. The acoustical reflections received are shown in the other illustrations on this page. P. Sachs, of our staff, who took this remarkable photograph underwater was asked: "Could you hear the bang?" and replied: "What, what did you say?"

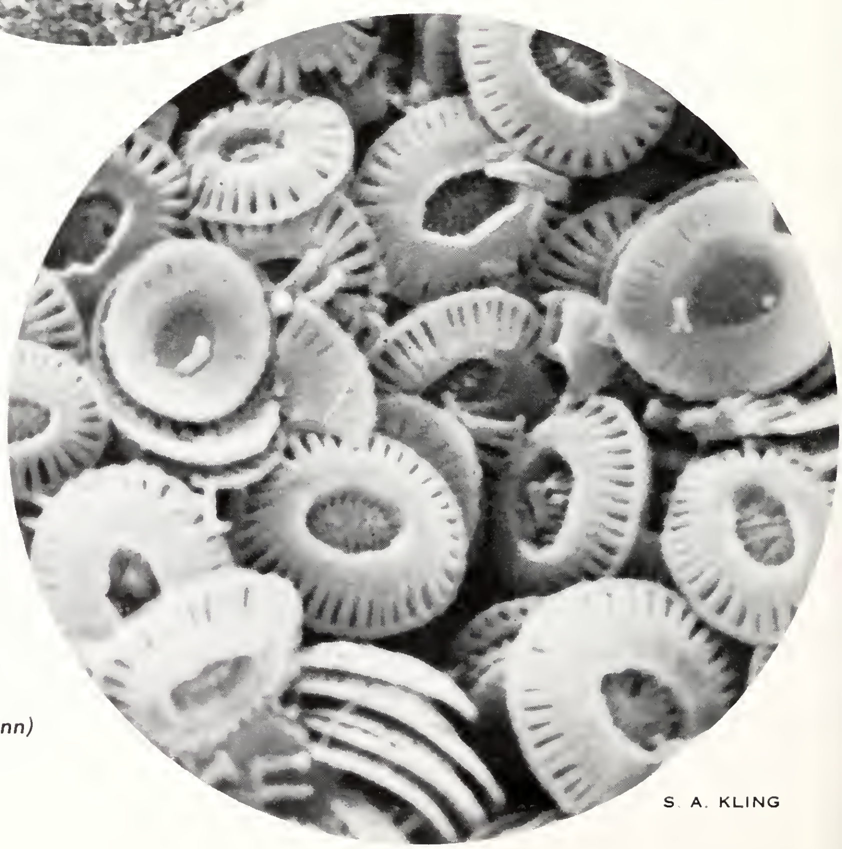


Big

Bigger



Biggest



The same sample of sediment is shown enlarged 100 times, 1000 times and 10,000 times, indicating that the white layers consisted entirely of the scales of an algae Emiliania huxleyi (Lohmann)

S. A. KLING

Coccolith Intrusion in the Black Sea Since the Ice Age

by D. BUKRY

Coccoliths, the skeletal remains of microscopic marine algae, are a major component of layered sediment in the deeper areas of the Black Sea.

CORES from the deeper parts of the Black Sea typically consist of very fine-grained sediment. Many of these sediment cores, particularly just below the sea bottom, are distinctly layered; white layers alternate with medium-gray layers. The individual white layers are usually less than 1 mm thick and are made up of minute particles of calcite (the predominant mineral of limestone). These particles were examined by light microscope, scanning electron microscope, and transmission electron microscope to determine the origin of the layers. Previous reports had suggested that the layers were composed of non-biological calcite or of formless calcite particles produced by bacteria.

The microscopic examination revealed that the white layers consisted principally of calcite scales from the skeleton of a species of tiny one-celled plant named *Emiliania huxleyi* (Lohmann). This species, a member of a group of free-floating golden-brown algae called Coccolithophyceae, is living today in the Black Sea and throughout the oceans of the world. During periods of rapid growth and reproduction, near-surface water can contain up to a million cells of *E. huxleyi* per liter; at this concentration the sea water looks milky.

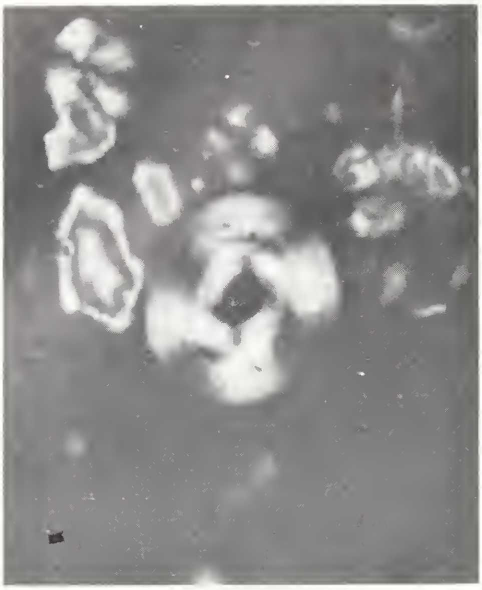
The calcite scales produced by *E. huxleyi* are small (2-3 micron) radially constructed button-shaped skeletal parts that are generally called coccoliths. Each individual organism produces many identical coccoliths, which upon the decomposition of the organism sink to the sea floor and may be preserved as a part of the sediment. In the Black Sea, over a period of the last several thousand years, *E. huxleyi* produced so many coccoliths that at times they were essentially the only kind of particle that was deposited on the sea bottom. The white layers in the Black Sea sediment contain billions of coccoliths in each cubic centimeter of material.

The alternating medium-gray layers of sediment contain other material besides the coccoliths of *E. huxleyi.* This additional material has been transported into the Black Sea by rivers such as the Danube, Dnieper, and Dniester. Among these transported particles, which were derived by erosion from rocks that are at the surface in areas drained by the rivers, there are large numbers of old coccoliths. These eroded and transported coccoliths belong to species that became extinct from 40 to 70 million years ago, during the Eocene and Late Cretaceous epochs. Below the zone of white layers (about 3 meters below the sea floor) only old redeposited coccoliths occur in the gray sediment.

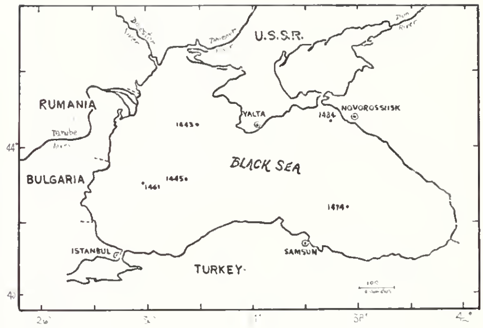
Therefore, over the past few thousand years the sediment deposited in the deep Black Sea has provided a record of alternating periods when either old transported coccoliths from land erosion or new coccoliths produced in the sea contributed most of the fine-grained calcite. Although the most abundant species present, *E. huxleyi,* first appeared in the oceans some 240,000 years ago, it was able to invade the Black Sea only after the last of the great continental ice sheets had vanished. The sea level raised by the melting of the ice, brought the Black Sea by way of the Bosporus and Dardanelles into communication with the Aegean and Mediterranean Seas and thence the ocean.

Detailed study of the distribution of coccolith species in the sediment of land-locked seas can yield important evidence about the geological history of such areas, as coccoliths can be used as tracers for marine conditions and for erosion of surrounding land areas.

*Publication authorized by the Director, U.S. Geological Survey



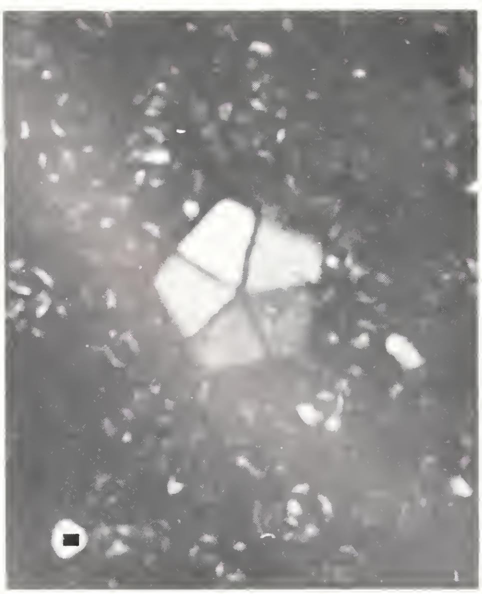
Tiny plant remains were found of species which became extinct millions of years ago. This is *Coccolithus bisectus*, enlarged 2000 times, from core No. 1443, found at a depth of 748 cm in the core.



The locations of the cores examined for coccoliths are shown, as well as the major rivers flowing to the Black Sea, which brought extinct species of coccoliths from eroded rock into the sea.

Electronmicrographs by D. Bukry. The scale bar on the lower left of each picture indicates one micron.

The esthetically pleasing coccolith, shown on our front cover, appear here only as tiny dots surrounding a pentagon shaped *Braarudosphaera bigelowi*, magnified 2000 times.



The black sediment from the Black Sea, obtained by a box corer is opened on deck and examined by Dr. Hunt. The square corer obtains an undisturbed core and was designed by the Institut für Meereskunde in Kiel.

TRACE METALS IN THE BLACK SEA

by

P. G. BREWER, D. W. SPENCER, and P. L. SACHS

ONE of the ironies of life is that in order to measure the few micrograms of many trace metals found in sea water one must first catch several kilograms of water. Thus, in the cold March weather of the Black Sea, we tugged, heaved, and cursed at water samplers weighing some 40 kg (80 lbs.) each when full.

Our interest in the trace metals, such as iron, copper, zinc, nickel, cobalt, and lead, in sea water extends far beyond merely determining how much is there. We would like to know how the distribution of these elements is affected by streams and rivers, and whether phytoplankton take up significant quantities of metals and, when they die, transport the metals to the deeps as solid particles. Also whether chemical considerations, such as the presence of hydrogen sulphide in a stagnant basin can remove the metals from seawater by the formation of insoluble compounds. Apart from these considerations, suspended particles influence the scattering and absorption of underwater sound and have an effect on the light penetration and the color of the sea.

Fine Filters

In order to examine the movement of these elements through the ocean, we filter our samples through very fine filter papers and analyze both the water and the collected particles. When planning our work for the Black Sea, we had noted previous observations, and knew that the stagnant deep water was separated from the oxygen-rich upper layers by a marked salinity change. We hoped that minute sinking particles might accumulate in greater quantities there. In this transition zone marked chemical changes must occur, and we arranged for detailed sampling across the boundary. To avoid contamination of the deep water samples by exposure to atmospheric oxygen, we had to use ultra clean laboratory conditions with a totally enclosed pressure filtering system using nitrogen gas.

Dark brown material filtered from the transition zone between the oxygenated surface water and the anaerobic deep water was found to be due to manganese oxide. Dr. Brewer (right) shows some filtered samples to Prof. G. G. Polikarpov, Deputy Director in Science, Institute of Biology of the South Seas, Yalta, whose valuable work is well known to the oceanographic community.

At each station our colleagues first lowered an electrode which measured the oxygen content of the water continuously. From this information we arranged our samples at various depths. One striking observation made early in the cruise showed that samples from the transition zone contained a large quantity of dark brown particulate material, obvious to the naked eye as it collected on the membrane filter. Samples a few meters above and below this zone seemed very low in suspended matter, much as we had hoped. The material seemed coarse grained and was probably formed from oxidation of material dissolved in the deep water.

We showed samples of this material to Russian scientists at Gelendzhik and to a visiting party from Sevastopol, but it seemed completely new to them. One explanation for this may be that the thin layer is difficult to sample.

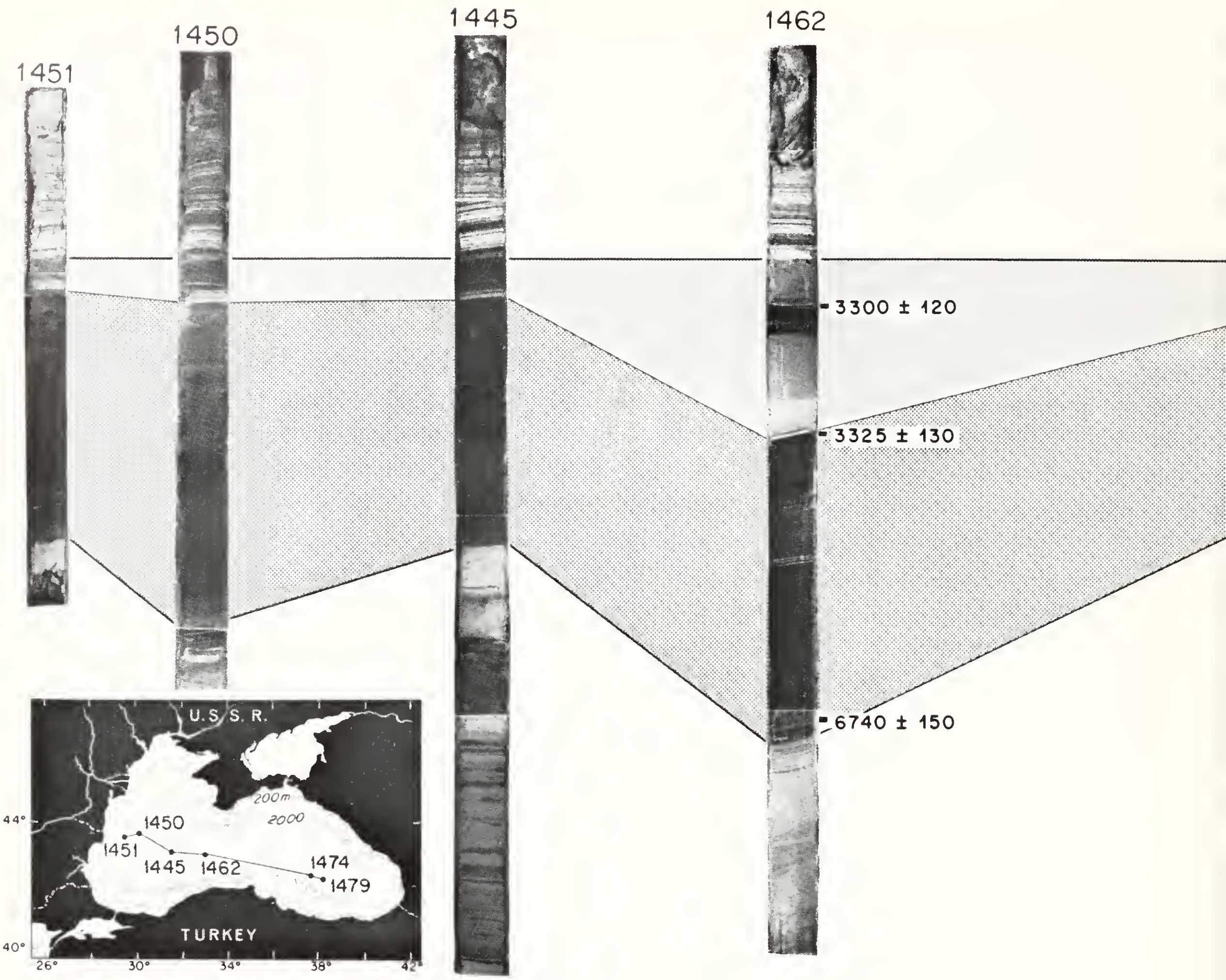
Once back in Woods Hole, we began to work on our samples. More than 130 water samples were analyzed by the fairly new technique of atomic absorption spectroscopy. The metals were chemically concentrated and then sprayed into the flame of the spectrometer. Discharge lamps which have a cathode made of the element of interest such as nickel, cobalt or lead are shone through the flame. Atoms of the sample formed in the flame absorb some of the light and the change in intensity of the beam is measured. A more powerful technique was available for the samples of suspended matter. These were pressed into pellets, about the size of an aspirin, in a stainless steel press and then placed in a nuclear reactor. Under the influence of neutron bombardment, radioactive isotopes are formed and the radioactivity of the samples is measured. From this we can determine the elements present. Previously, this involved a great deal of labor, but modern detectors and electronics are such that we can determine up to 14 elements at the same time in one sample.

Manganese

The dark brown material that puzzled us was found to be due to manganese, which has accumulated in the deep waters of the Black Sea to a level five hundred times greater than that found in the normal ocean. The manganese separates as an oxide (much as iron becomes rusty on exposure to air) forming the coarse material that was filtered out. Our discovery can now be seen to have wide significance. Oceanographers have speculated for years that uptake on the surfaces of iron and manganese oxides scavenges many metals, thus, controlling the level of trace metals in the oceans; thereby in one theory providing an explanation for the marked loss of these metals from the ocean over geological time, and accounting for the enrichment of such elements as cobalt, nickel, and zinc in the manganese nodules which are spread throughout the ocean basins of the world. Chemists, too, have often used coprecipitation (or scavenging) with manganese oxides in the laboratory to strip metals from solution. A naturally occurring precipitate in mid water such as the one we found gives us a unique chance to test this theory.

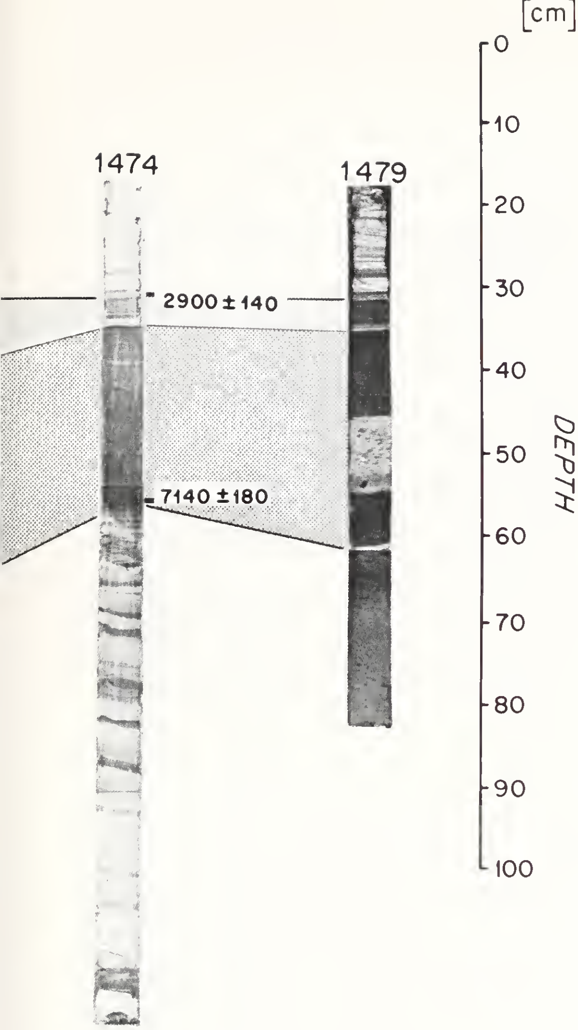
Undissolved Metals

Data obtained for the other metals is just as interesting. We know that anoxic basins become stagnant because there is little or no flushing of the deep water, thus they tend to act as a trap for elements such as manganese or iron. However, the presence of hydrogen sulphide leads to a chemical reaction in which many highly insoluble metallic sulfides are formed. For instance, chemistry text books tell us that for every atom of zinc in a sulfide solution there are 400,000,000,000,000,000,000,000 solid particles of zinc sulfide. In other words it is highly unfavorable for the zinc to remain dissolved. Thus we would expect to find no dissolved zinc in the deep waters of the Black Sea. Of course these vanishingly small numbers do not apply in any real sense to the conditions in the sea, textbooks are not adequate to describe the ocean, and may only be used as a starting point. Our analyses show that small but significant quantities of many metals are present in the deep waters of the Black Sea, and the problem is to explain just how and what and to characterize the equilibrium found in nature. Copper, zinc, cobalt, and molybdenum are all markedly depleted in the deeps and many months of work will be needed before we can give an account of this complex environment.



Three major events in the geological history of the Black Sea can be traced across the sea in the cores shown here. The numbers alongside two cores indicate the events in years before the present (BP) as determined by carbon 14 measurements. The insert shows the locations where the cores were collected.

Recent Sediments of the Black Sea



by D. A. ROSS, E. T. DEGENS,

J. MacILVANE, and R.M. HEDBERG

ONE of the more unique aspects of the Black Sea is that a shallow sill, about 50 meters deep, separates it from the Mediterranean Sea. Thus, a small drop in sea level could isolate the Black Sea from the Mediterranean and the Atlantic Ocean. We know that sea level did drop, perhaps as much as 120 meters, in the last 20,000 years. In many areas of the world this lowering caused the shoreline to move seaward and exposed large parts of the continental shelf. Places like the Red Sea, which is also separated from the open ocean by a shallow sill, started to dry up and eventually became highly saline basins. The Black Sea, because many large rivers like the Danube empty into it, had a different response. Instead of drying up, it became a fresh water lake; in fact, it may have been one of the largest fresh water lakes in recent times, covering an area of over 410,000 square km. The combined area of the five Great Lakes in the U.S. is about 245,000 square km.

The Black Sea then gives a scientist the opportunity to study a rapidly (geologically speaking) but well-documented changing environment. Geologists have studied these sea-level changes by examining cores of marine sediments, but in many instances they are frustrated because bottom-living organisms churn and mix the sedimentary layers, often confusing or obliterating the record. But in the Black Sea this problem is absent since the bottom waters have no oxygen. In such an environment, life for benthic organisms (except some bacteria) is impossible, and thus the sedimentary record is undisturbed.

A further advantage offered by the Black Sea is its relatively high sedimentation rate of about 10 cm per 1000 years, which can be compared with the average sedimentation rate of about 1 cm per 1000 years for open-ocean environments. Therefore, events that occurred within the last 10,000 years will be expressed within the top 10 cm of normal deep-sea sediments, whereas in the Black Sea the record will be spread over a 100 cm interval. This expanded record is, in most instances, easier to interpret.

Our aim in studying the Black Sea sediments was to get representative coverage, and in some localities try for very long cores. We were successful in the first objective, less so in the second.

Core 1474

After the collection of our samples at sea, and the subsequent return of the 'Atlantis II' to Woods Hole with the material, we started our studies. We had collected over 600 feet of cores and quickly realized that a detailed analysis of all this material would take years. To bring this to a more reasonable period of time, we selected one core—1474— as a reference and studied it in detail and subsequently related all the other cores to it. Core 1474 was selected because it was collected in an area that we suspected to have a relatively low sedimentation rate, and thus would extend as far as possible back in the geologic past.

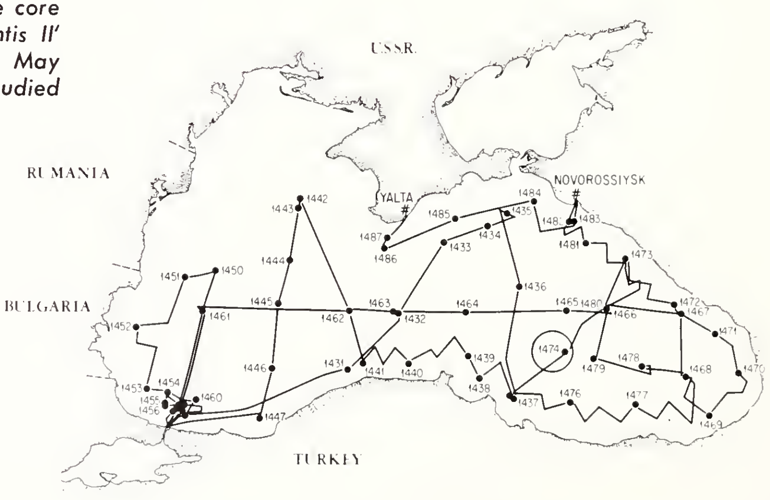
Three Units

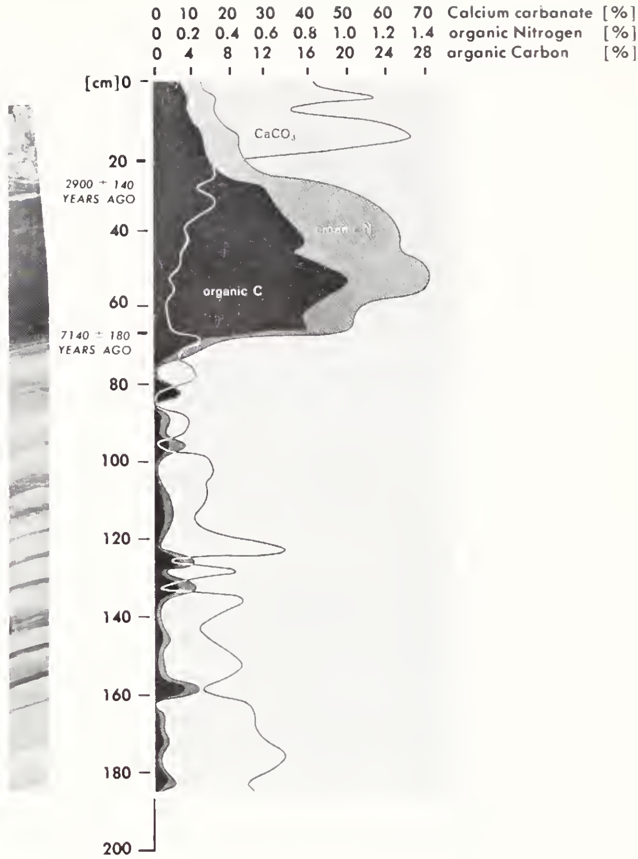
The core shows three distinct units. The uppermost unit contains as much as 70 percent calcium carbonate and extends to about 30 cm below the surface. This is composed of finely divided layers, which previously were thought to be of inorganic origin. Electron photomicrographs of these layers showed that the layers were composed of the skeletons of a microscopic planktonic organism called Coccolithophorids.* This thin, finely-laminated sequence can be seen in most of the cores that we collected and individual layers can be correlated, in some instances, across the entire basin, a distance of almost 1000 km.

The layers clearly indicate some sort of periodic sedimentation. Russian scientists have counted the individual layers and find about 100 of these to a centimeter. If each layer is due to a yearly event, the deposition of this carbonate sequence should have taken about 3000 years. A carbon 14 age determination from the base of this sequence indicates that it is 2900 ± 140 years old. This age supports the hypothesis that these layers are due to a yearly event, perhaps a yearly plankton bloom.

*See: Page 21

The ship's track and the core stations made on 'Atlantis II' cruise 49 in April and May 1969. Core 1474 was studied in detail.





Three distinct events, related to the rise and fall of sea level, with changes from fresher to saltier water, are indicated by the carbonate unit on top of core 1474 K, followed by the dark organic unit from 30 to 70 cm down, and the alternating light and dark layers below.

The second sedimentological unit is an organic-rich sequence about 40 cm thick that underlies the Coccolithophorid zone. The presence of large amounts of organic material in marine sediments is surprising. These sediments were examined using an electron microscope and numerous structures resembling biological membranes were observed* which are not usually found so deep in marine deposits. They may be remains of some previously unknown microscopic organism that inhabited the Black Sea many thousands of years ago.

The third unit is an alternating sequence of light and dark sediment that contains relatively lesser amounts of organic and carbonate material. None of our cores penetrated below this unit.

Fresh Water

Obviously the differences between the three sequences relate to changes in the environment. To understand this, a short description of the recent geologic history of the Black Sea is necessary. During the interval from about 12-20,000 years ago, the Black Sea was isolated from the Mediterranean due to the glacial lowering of sea level. In the later part of this interval, melting of the ice was intense, and fresh water ran into the Black Sea, making it a fresh water lake. Sea level continued rising during this period until connection with the Mediterranean was re-established somewhere between 7 to 12,000 years ago. At that time, salt water from the Mediterranean started entering the Black Sea and the salinity slowly started to increase. It probably was not until about 3000 years ago, when the carbonate material was beginning to be deposited, that the salinity conditions reached those we find in the Black Sea today. Thus, the third, or lowest sequence, was deposited during fresh water conditions when periodic flooding carried large amounts of material washed from the land into the basin. The organic-rich sequence, the second unit, was deposited as the flooding started to decrease, and the Black Sea was going through a transition from fresh water to its present salinity. The uppermost unit started being deposited when the Black Sea had reached its present salinity conditions. These changes in the environment were in most instances rather gradual, however, some rapid events are suggested by the fine white layers present in the organic-rich unit. These thin layers are usually composed of Coccoliths, suggesting that conditions favorable for their growth prevailed at least for a short time, prior to their period of intense growth about 3000 years ago.

So far only the more general implications have been established, concerning the relation of climatic and sea level changes. It is clear that periodic events of shorter duration, perhaps as short as yearly cycles, have influenced deposition over the last several thousand years. The ability to correlate changes in the depositional environment of the Black Sea with this precision presents possibilities for detailed interpretations which are rare in marine geology.

*See: Page 13

Fossil Water

by F. T. MANHEIM

MOST of the cores of sediment taken from the upper layers of the ocean bottom are clayey in appearance and contain some water. When squeezed out, such waters can tell some useful tales to oceanographers. The fluids may retain some of the original composition of waters buried in the history of the sea and tell us how the chemical composition of ocean water may have differed in earlier times. The waters —called pore waters—provide a sensitive record of reactions between the sediment and the water and may show the migration of fluids. For instance, in pore water studies made in drill cores off Florida, the author found movements of fresh water from the land by subterranean aquifers as far as 120 kilometers from shore.

Pore waters also have long been known as sources of nutrients. Recently, Dr. P. Mangelsdorf and his associates at this Institution reported that only 10 percent excess of potassium in the sediment waters could supply several times as much potassium to the ocean as all the streams and rivers in the world. Drainage from the land had been considered as the principal supplier of potassium which is one of the major elements in the salt content of the ocean. The excess potassium in the sediments may occur due to the breakdown of mineral particles, such as volcanic ash.

Oil Clues

Hydrocarbons found in pore water may provide oil-finding clues to petroleum searchers and—on the negative side—may be the medium by which poisonous pollutants which were deposited in the sediments are released to the overlying waters.

Present Black Sea salinity normally ranges from 17-18°/oo (parts per thousand) near the surface to between 22 and 23°/oo in the deepest waters. However, we know from the work of Russian scientists that the salinity of the Black Sea was highly variable during the Pleistocene Epoch, and was probably unstable back to Cretaceous time (80 million years ago). The relatively narrowness of the channel (and earlier channels) connecting the Black Sea with the salty world oceans is responsible for the variations in salinity. With rise and fall of the sea surface in response to ice accumulations on land, the channels have changed drastically in volume and at times have dried up entirely. The ages of known fluctuations in Black Sea levels probably require revision and the estimated heights and depths of the sea levels shown in the profile are only approximate, but our illustration gives a qualitative idea of the relationships between the ages, water levels, and salinities.

During the latest (Wisconsin or "New Euxinic") ice age maximum the Black Sea was entirely cut off. It probably received less water from rainfall than it lost through evaporation, but excess stream runoff, especially that from melting glaciers led to substantial freshening of the Black Sea. Soviet scientists continue to dispute whether the Black Sea was a completely fresh lake, or retained brackish bottom waters. Evidence from changing flora and fauna in the sediments of the earlier Black Sea proves that the rises and falls in sea level must have caused drastic changes in the salt content of the waters. Although oxygenated waters now extend only 100-200 meters below the sea surface, fossils in cores suggests that oxygenated waters existed deeper during earlier stages. We do not know how much deeper, or indeed whether the whole Black Sea became oxygenated at intervals.

After World War II, S. W. Brujewicz and his colleagues at the Institute of Oceanology, U.S.S.R. Academy of Sciences, made use of the then newly-developed Kullenberg piston corer to obtain sediment cores as long as 13 meters from the Black Sea. The water pressed from the sediment cores showed startling confirmation of the hypotheses concerning fresher waters in earlier Black Sea stages. Most of the data showed consistently lower salinities in the pressed out water (pore water) with depth in the cores. The salinities dropped as low as 11°/oo, far lower than any values found today in the Black Sea. Yet even these values were probably higher than the original salt content of the pore water, since salt must have continually diffused downward from the more concentrated solutions above, and smoothed out more abrupt variations in original salinity.

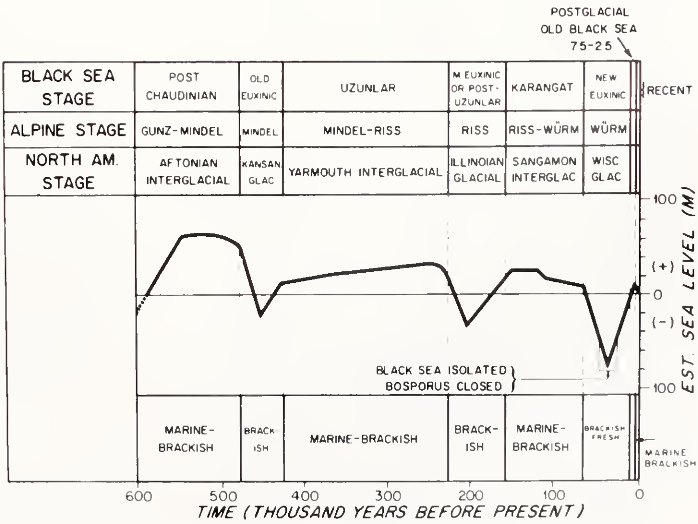
Pressed Water

Using squeezing apparatus on board ship we set out to confirm the data of the Soviet workers, to extend them if possible, learn of possible patterns of fluid migration or consolidation in the sediments, and study interactions between the fluids and the enclosing sediments. The sediments were pressed in a stainless steel squeezer similar to those used by the Soviet geochemists (sediments are sealed in by rubber gaskets and clean pore water is forced out through ordinary laboratory filter paper). A new, rapid, and temperature-compensated hand refractometer permitted immediate determination of salinity on only a drop of fluid, with an accuracy of about 0.2°/oo in less than one minute. Other samples were fused in polyethylene pipe or in glass ampules with the help of a propane torch and were saved for later detailed analysis in the laboratory. Still other samples were analyzed immediately for alkalinity or given to the chemists on board (headed by K. Grasshoff). The latter group added the samples to the "AutoAnalyzer program," and analyzed simultaneously for phosphate, nitrate, ammonia, nitrite, and silicate.

The work done on board soon confirmed the Russian findings of decrease in salinity with depth. In fact, new record low salinities of 6°/oo were obtained in station 1442P, east of Sevastopol off the Crimean coast. However, near the Bosporus a reversal or increase in salinity with depth in the sediment core was obtained.

The data also revealed the activity of microbes in oxydizing organic matter by using dissolved sulfate from the pore water as their source of oxygen, even though the water itself contains no oxygen.* At the same time nutrient salts such as ammonia and phosphate are released by this activity.

*See: "Nitrosocystis oceanus," by S. W. Watson and C. C. Remsen. Oceanus, Vol. XIII, No. 4, Oct. 1967.



The changes in sealevel during alternating cold and warm periods in the last 600,000 years. The dates of the periods have been revised, but the diagram shows a reasonable picture of sea level and salinity conditions.

The relative consistency of the salinities in the pressed out core water over surprisingly large areas encouraged me to plot all available data, Soviet and ours, to see whether one could map salinities at given depths in the sediments from the sea bottom.

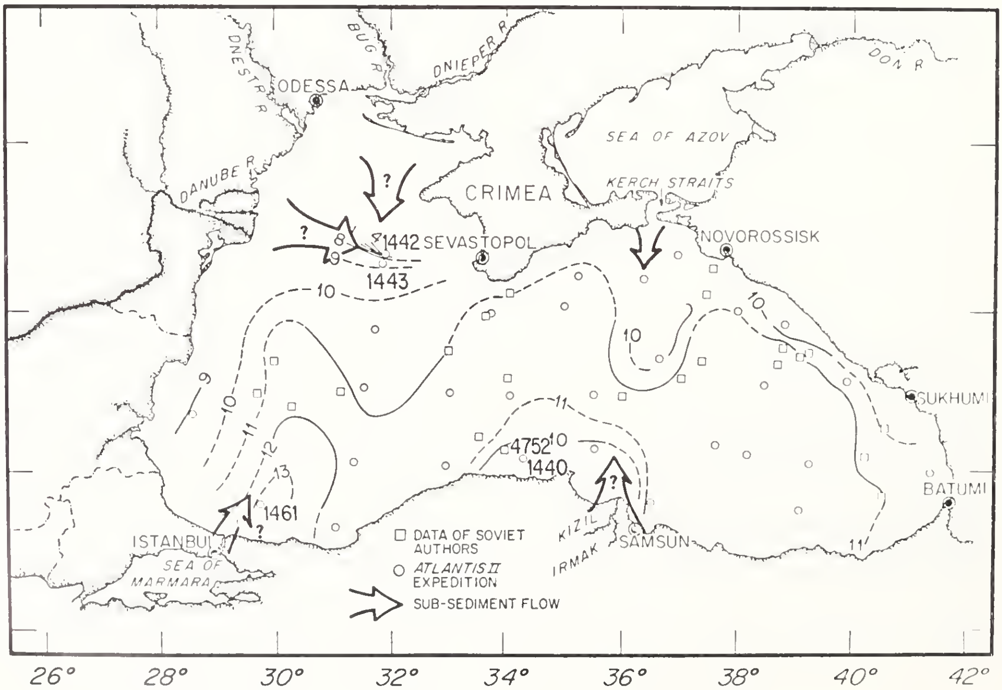
The conclusions from the map of interstitial chlorinity** at depth of 2 meter in the sediment are:

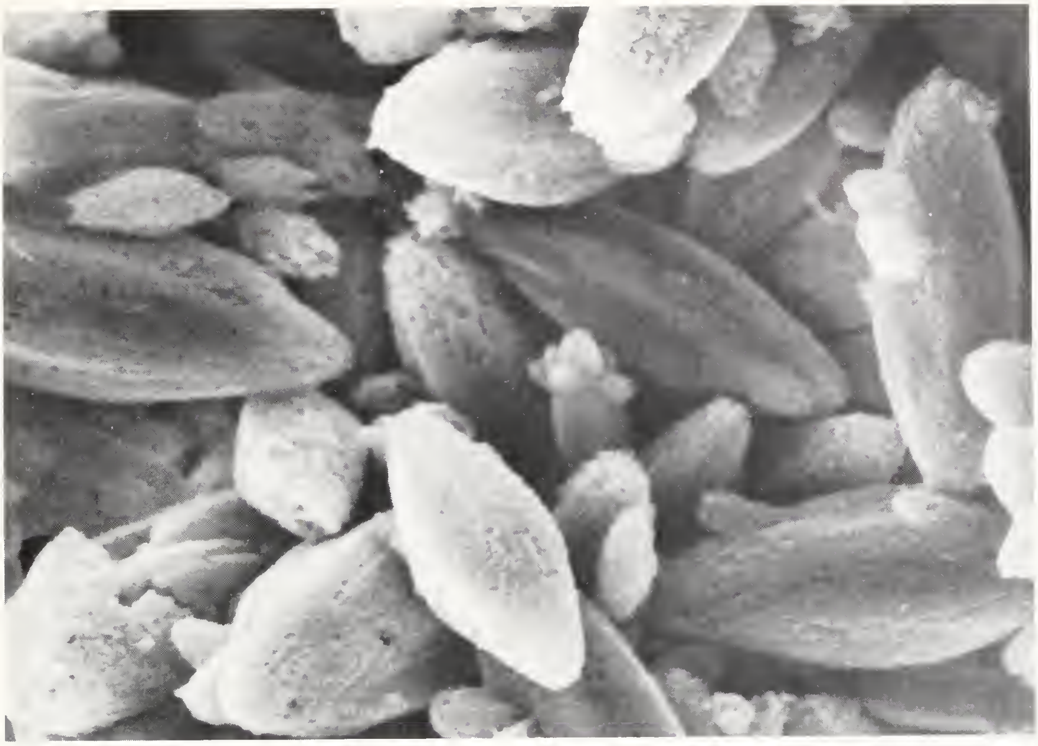
Pore fluids become less salty with depth over nearly the entire Black Sea, probably because of the influence of fresher waters incorporated in the sediments during the glacial periods. The only exception to this occurs on approaching the Bosporus, where salinities decrease less and less with depth, and finally begin to increase with depth. This remains to be explained. Several areas near major present and past river systems become fresher than average with depth; both here and in the vicinity of the Bosporus we cannot exclude the possibility that waters are now moving or have moved toward the Black Sea via underground pathways. The very sharp decrease in salt content with depth at station 1442 suggests that there may be submarine discharge of fresh water from extensions of land aquifers now, or that there may have been such discharge in the recent past. It is significant that we encountered no reversals in salinity within a core sequence. This may suggest that we have not penetrated any "warming" interglacial period earlier than the present with its presumably higher salinities. We can also conclude that the Black Sea formerly had bottom water salinity at least as low as 10°/oo (compared with more than 20°/oo today).

Analysis of deuterium and oxygen isotopes now being done on the pressed out waters by W. Deuser of this Institution should tell us more about where the ancient Black Sea waters came from.

**Chlorinity is related to salinity by a factor of about 1.6.

The "fossil" chlorinity of the Black Sea sediments at a depth of two meters below the seabottom, as found by squeezing water from the sediments. The contours are in parts per thousand (°/oo). The arrows indicate possible underground fresh water sources.





The fossil record of a short-lived plankton bloom—consisting of odd shaped particles of aragonite (a variety of calcium carbonate) was found in the sediments. Particle size is 10-40 microns.

Stable-Isotope Geochemistry

by W. G. DEUSER

STABLE-ISOTOPE geochemistry, the science of variations in the natural abundances of stable isotopes, (species of an element which differ by weight) is barely more than a quarter century old. In those few years it has contributed immensely to our understanding of many processes in general geology, biology, and oceanography. As an example, it has given us a rather precise idea of past climates over large parts of the earth as well as of the salinities of inland seas in the remote past. The basic principle of isotope geochemistry is the fact that many substances, whether organic or inorganic, may contain two or more stable isotopes of a particular element in slightly varying proportions. These proportions provide clues to the source and history of the sample whether mineral, vegetable, or animal. Especially useful elements in this regard are carbon and oxygen. In the case of carbon, for example, the ratio of the heavy isotope to the light isotope varies in nature by about 10 percent. On a mass spectrometer it is easy to measure differences which are about one thousandth of that range. This then gives us a means of sub-dividing natural carbon-containing substances into many groups based on their isotope ratios. Theoretical as well as experimental data accumulated over the years help us to reconstruct the conditions under which the substances were formed.

Uniformity

While in the Black Sea, we collected a variety of samples including marine life, water, and sediment. After our return to Woods Hole we analyzed their stable-isotope content to find out more about the past history and present constitution of that unique body of water.

Analyses of plankton samples collected from the upper 100 meters of the water at stations spread over most of the Black Sea showed somewhat surprisingly that the carbon in the plankton is quite uniform throughout that sea. Earlier investigations had shown that the carbon-isotope ratio of the plankton is determined by the photosynthetic process in the small algae and that the ratio is very sensitive to the rate of photosynthesis and to the chemical and physical conditions of the environment. The isotopic uniformity of the plankton, therefore, is a sensitive indicator for the rapid mixing and homogenization of the near-surface waters in the Black Sea. That, of course, stands in stark contrast to the near absence of vertical mixing which is responsible for the stagnant conditions at depth.

Tremendous Bloom

We made one of our plankton tows in a mass of water in which a tremendous plankton bloom was taking place. This is a sudden population explosion of algal cells when the conditions in the water are just right to stimulate rapid cell division. Our tow through this bloom yielded several thousand times as much plankton as is normally obtained. In the parcel of water supporting the bloom, there was almost as much carbon bound in the cells as there was in the water in a form available for plant growth. This beginning scarcity of available carbon was reflected in the isotopic composition of the cells and represented the first documented instance of a beginning carbon shortage in the marine environment. Most commonly the other essential life-supporting ingredients are depleted long before the supply of carbon is affected.

Biological Use

Isotopic analyses of the carbon dissolved in the water itself led to some other unusual discoveries. Quite in contrast to the open ocean we found that the heavy isotope of carbon became more and more scarce with greater depth all over the Black Sea basin. This tells us that a greater and greater portion of the dissolved carbon has at one time gone through the process of photosynthesis, that is to say that in one form or another it was used biologically. We call this type of carbon "biogenic" (Greek for arising from life). The reason for the increasing amounts of

These pentagon-shaped plates were found among the coccoliths in Black Sea sediments. They are Braarudosphaera bigelowi. In a different view it is shown that many of the boxlike algae were deposited without breaking up.

biogenic carbon at depth lies in the stagnancy of the deep waters. Many of the organisms which live in the thin layer of oxygenated water at the top will after death fall to the bottom where further decomposition of their remains is promoted only by the bacteria which do not depend on oxygen. Although this process is slower and less complete than oxidation which takes place in the open ocean, the products of bacterial decay keep accumulating in the deep waters of the Black Sea and are not carried away in any efficient manner. We can estimate that the deep water contains the decomposition products of organisms which rained down from the top over the past 2000 years.

The isotope measurements on the water also allowed us to calculate the extent to which the hydrogen sulfide in the Black Sea originated from the sulfate in the water and how much was derived from decaying organisms. We determined that between 3 and 5 percent of the hydrogen sulfide comes from the organisms and that the influx of dead organisms to the bottom may have been steadily increasing over the past 2000 years. Such an intensifying rain of organic debris implies either a growing productivity of the Black Sea during that time or a progressive thinning of the aerated top waters resulting in the death of increasing numbers of organisms.

Many Cycles

Isotopic analyses of some of the materials in the sediment give us more direct information on the conditions at the time of deposition of the successive layers of sediment. So far we have looked at the carbon isotopes of the organic matter and at both carbon and oxygen isotopes in the fine white carbonate layers found in the upper meter of the sediment. The organic matter and the carbonates reflect the climatic conditions at the time of their formation. The ratios of the carbon and oxygen isotopes in these substances are especially sensitive to temperature and salinity variation. By analyzing these layers, covering the last 7000 years, we detected about a dozen cycles varying in duration from a century to nearly 1000 years.

Fossil Bloom

In the course of the work on the sediments, the isotopic analyses also led to the discovery of a pronounced but short-lived occurrence. Although our investigations are not yet complete, we believe that we have found the fossil record of a plankton bloom which probably lasted for only part of one season. While analyzing the isotopic content of a number of carbonate layers, all of which were thought to be composed primarily of coccoliths, we came across one sample which gave different results from all the others. Earlier work we had done on a variety of lime-forming marine algae suggested that this carbonate could not be coccoliths but was formed by another type of algae. The carbonate is not calcite as are the esthetically pleasing coccoliths. Instead the electron microscope and the X-ray diffractometer, an instrument which determines the crystallographic makeup of a substance, revealed that the carbonate consists of odd-shaped particles of aragonite. Thus far we have not identified the specific type of algae responsible for this unusual carbonate layer. It appears to be the only such layer deposited during the last 7000 years. The layer is so thin that it probably was deposited in less than one year. The isotope analyses indicated that the carbonate originated in warm water quite near the surface and that it was formed by one of a group of green algae. We plan to investigate this phenomenon further and hope to find out what may have lead to this unique bloom some 6 or 7000 years ago. It is an intriguing thought that whatever unusual circumstance was responsible might also have left a record in the sediments of regions other than the Black Sea.

Bottom Photographs

by A. C. VINE

The most commonly encountered type of bottom with a low contrast, mottled appearance. It appears that a few centimeters of the near surface mud has tended to collect in somewhat random clumps. Typical clump separation is 2 cm. It is too soon to speculate whether this is a result of gas evolving from the bottom, from a coagulating type of sedimentation, or from other causes.

Photograph from Station #1468, depth about 1900 meters.

WHEN the 'Atlantis II' radio operator A. T. Johnston first saw the nondescript grey mud samples come up from the depths of the Black Sea, he wondered how successful our underwater photography would be. Alex's remarks were well taken since he had done much underwater photography, including some of the early photographs taken during the search for the lost submarine 'Thresher' when he was working with the Institution's geophysics group.

How bottom photographs may provide information has been described in the excellent book "Deep-Sea Photography."* The 'Atlantis II' cruise into the Black Sea gave us a chance to photograph an interesting marine environment where little deep bottom photography seems to have been done.

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*"Deep-Sea Photography", Ed. J. B. Hersey, The Johns Hopkins Oceanographic Studies: Number 3, The Johns Hopkins Press, 1967.

Among the reasons to take bottom photographs in the Black Sea area were: to find evidence of geological activity, to see if there were any remains of biological or physical debris, and if anything unusual might show up in an environment lacking in oxygen. We also were interested to find evidence of present or recent water motion which might show up as bottom ripples or drag marks. Finally, we would broaden the geographic base of bottom photographs in enclosed basins to gain a better global perspective and to make such views available to other oceanographers.

We could not find many bottom photographs previously made in the area. Dr. R. Hurley of the University of Miami had shown me some of the few deep photographs taken from the R.V. 'Pillsbury' in the Black Sea during 1965. It seems likely that Russian oceanographers who have taken excellent bottom photos in the Atlantic and Pacific Oceans have taken some photographs, but no published ones are known to me.

from the Black Sea

An example of occasional figurations on the bottom is shown in this photo taken at station 1452 at a depth of about 2180 meters. Because organic material is not exposed to predators or to oxidation on the way down and on the bottom, dead marine life or tree branches might retain a semblance of their general shape for a long time. Resilient wooden twigs were found in cores some 4 meters below the sea bottom and provided an indication of the length of time that objects may remain unchanged.
We do not know what the objects are in this photo.

Equipment

The equipment consisted of a frame holding two downward pointing Edgerton cameras, one downward pointing electronic flash and a pinger to indicate the height of the camera frame above the bottom. All components of the camera assembly were self contained, battery operated, and pre-set.

Each camera contained 50 feet of 35 mm Tri X or Pan X film. The film transport and the electronic strobe light were synchronized. Rather than adjusting both cameras for the same focal distance and attempting to make stereo pairs, it was decided to focus one camera for 3 meters off the bottom and one for 5 meters off the bottom to make sure that at least one camera would be in focus. Most of the films were developed aboard ship so that the results could be checked and any necessary changes could be made between lowerings. Apart from some preventive maintenance, the cameras performed well. Although some change in technique might have been advisable, it was decided to leave well enough alone.

A typical problem was that, after being assembled, the cameras were checked by listening to the motors run through a few test frames. Since camera lowerings usually followed coring with the big winch, this acoustic check occurred during the confused racket of the core recovery operations. This caused an occasional needless disassembly and rechecking of the cameras. Perhaps it would be a good idea to bring a stethoscope along!

Maintaining the camera frame from about 3 to 5 meters off bottom to keep at least one camera in focus while the ship was drifting for about one hour, was an essential and somewhat critical operation. In principle it was a relatively easy standard technique. The 12 kHz pinger on the camera frame sent out uniformly separated pings. The echosounder on the ship received and recorded both the outgoing

and the bottom reflected signal. If these two pings arrived with a time separation of 5½ milliseconds or an indicated depth difference of 4 meters, then the camera frame was the correct distance above the bottom. If the arrival time separation became longer, cable was let out. If arrival time separation became less, the cable was hauled in. If the bottom was irregular and the two arrival time traces blended together, we hoped that the camera would merely plow mud and not catch on the bottom.

Controls

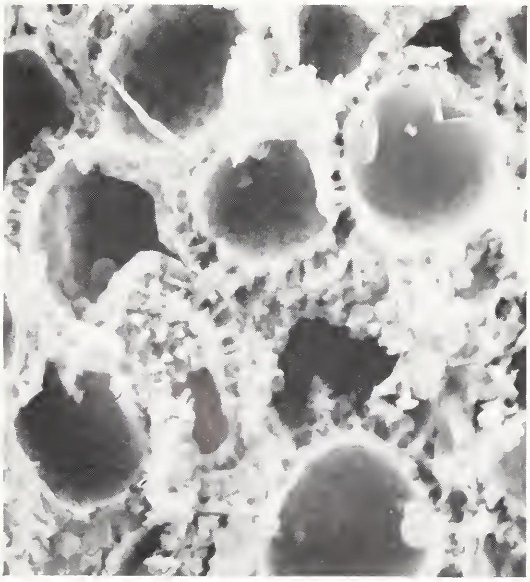
Two factors making bottom focusing difficult was that the large trawl winch was not too adaptable to precise control, and that the clock rate in the pinger was slightly different than the clock running our new precision echosounder recorder. New instruments are apt to acquire acronyms and this one soon was named DCR, for: "Digital Correlation Recorder." However, the recorder's versatility in being able to make certain fine adjustments compensated somewhat for other difficulties.

Seven camera lowerings were made in the central and eastern portion of the Black Sea. The locations were determined when time was available to lower the cameras and by the desire to photograph in depths where any peculiarities of an environment lacking oxygen might be most conspicuous.

About 50 pictures were taken on each camera on each of the seven lowerings. About two thirds of the time during any one run the camera seemed to be too close or too far from the bottom. In many of the remaining pictures it is difficult to tell whether the bottom is quite featureless or whether it was a poor negative. However, each film strip had at least a few interesting pictures. For rough purposes, it can be assumed that these photographs were taken about 4 meters above the bottom and that the overall picture size represents about a 2 x 3 meter segment of the bottom. We plan to print all the negatives with a special printer which brings out much detail in bottom photographs, and hope that with these better prints it will be possible to give more satisfactory explanations than has been possible so far.

Acknowledgments

As usual there was great cooperation among the scientific party as well as by the ship's force. Our primary underwater photographer Mr. D. M. Owen was not on board for this cruise but he assembled the equipment, supplies, and spare parts so well that both cameras worked on each of the seven lowerings.



Dinoflagellates from Black Sea sediment

PALEONTOLOGIC STUDIES

by F. T. MANHEIM

STUDIES of fossil organisms in sediment cores are important to date particular layers and shed light on the conditions of the environment when the sediments were laid down, as well as to further understanding of the organisms themselves. A variety of organisms such as bivalve molluscs, snails, bryozoa, benthonic foraminifera, sponges, worms, and ostracoda are found in the shallow water sediments of the Black Sea, and extensive stratigraphic descriptions of Black Sea sediments in the northern coastal zones are available based on the presence of bivalve molluscs.

However, a paleontologic attack encounters special problems in the deeper parts of the Black Sea. In his pioneering studies of samples recovered by the Chernomorets Expedition of 1890, N. I. Andrussov noted the virtual absence of recognizable skeletons of carbonate organisms in sediments below the deep oxygen-free layers of the Black Sea. Only diatoms and a few stray foraminifers, ostracodes, sponge spicules and other minor forms (probably transported from nearshore areas) were found here, even though the sediments contained much extremely fine carbonate. The carbonate was believed by John Murray, of the Challenger Expedition fame, to be inorganically precipitated, after he examined specimens sent to him by Andrussov. Subsequent Russian workers have held several conflicting hypotheses concerning the origin of the carbonates.

Bottom Dwellers

Since bottom dwelling organisms (except bacteria) cannot live in the present deeps of the Black Sea, attention turned to microplanktonic hardpart-bearing organisms which on death might settle on the bottom and be preserved. Radiolaria and planktonic foraminifera, so useful for dating studies in cores taken from the deep oceans, seem to be poorly developed in the lower salinity water of the Black Sea. However, silica-bearing diatoms and spores and pollen appeared to promise useful data on the sediments. We were fortunate to have secured the cooperation of a number of specialists who are currently studying both types of organisms.

Two new developments occurred in the study of the earth's geological history. Dr. D. Wall and Mr. B. Dale of this Institution discovered during studies of dinoflagellate distribution in cores from the Red Sea that these fossilized organisms could be used to investigate the geological history of the area. Preliminary examination of Black Sea cores shows them to be rich in dinoflagellates. The organisms are of particular interest because in addition to the stratigraphic value their presence or absence in sediment cores indicate marine versus non-marine conditions of sedimentation.

Breakthrough

The most exciting faunal breakthrough occurred in an unanticipated area: coccolithophorids. The plates, or coccoliths, of these minute (2-20 microns) organisms make up the bulk of chalks, such as in the "White Cliffs of Dover" and are widespread in the tropical oceans. However, although living species had been reported in shallow water regions of the Black Sea, they were not reported in detailed microscopic accounts such as those of Andrussov and Murray, nor noted other than as a curiosity in subsequent studies. Since the earlier detailed studies were performed before the availability of the electron microscope, (coccoliths can be discerned by microscope only under the highest magnification), the cooperation of Dr. D. Bukry, U.S. Geological Survey at La Jolla and Drs. S. A. Kling and M. K. Horne of the Cities Service Oil Co., Tulsa, was obtained to investigate possible calcareous organisms in the fine sediments.

Preliminary investigation by scanning electron microscope of sediments from several stations in the Black Sea revealed that the "amorphous carbonates" were virtually entirely composed of one species of coccolithophorid, *Emiliania huxleyi*.

Through the use of the paleontologic tools, we look forward to a host of new insights about the organisms themselves, the age of their enclosing sediment layers, the temperature, salinity and productivity of ancient Black Sea waters, the nature of past land plants and climate in areas surrounding the Black Sea, and perhaps some surprises.

A Microbiologist's View

by H. W. JANNASCH

To the marine biologist, the extreme conditions of the Black Sea pose several vexing problems that, if solved, promise a wealth of information. The question, which of those unique features is a cause and which is a result of biological activities, is as fundamental as the chicken-or-egg question.

The life of the commonly known marine flora and fauna, phytoplankton, zooplankton, and fishes, is restricted to the uppermost surface layer separated from the anoxic deep water by an oxygen/sulfide interface. But those deep waters, more than 4/5 of the Black Sea's volume, are by no means lifeless.

In geological times, the microbial degradation of plant and animal remains has consumed all of the oxygen in the deep waters making it uninhabitable for those animals that need oxygen for breathing. During the course of evolution, a specialized group of microscopic animals has learned to use materials other than oxygen for breathing, consequently, the larger part of the Black Sea became the sole domain for "anaerobic" bacteria.

The most plentiful of the materials that can be used for anaerobic respiration in seawater is sulfate. The left-over product is the smelly hydrogen sulfide. Sulfide and oxygen eliminate each other quickly, producing the definite interface: oxygen and aerobic life in the top layer; sulfide and anaerobic life in the deep waters.

This interface acts like a bottom with holes: some of the organic material originally produced by plants in the surface waters are retained in the upper layer, others are lost to the abyss. This sinking of the heavier particulate material constitutes the basis of life, the source of energy, for the rich population of anaerobic microorganisms in the deep anoxic waters.

Active Centers

Taking samples throughout the water column and culturing the various types of bacteria in hundreds of tubes, we found first of all two extensive centers of active sulfide production: one directly below the interface and another one just above and in the surface layer of the sediments.

The ingenuity of microbes in finding ways to live in adverse environments does not stop with the respiration of sulfate. We isolated bacteria from the upper layers of the anoxic waters which used nitrate for the same purpose. Furthermore, the high content of methane gas dissolved in the deeper Black Sea water indicated the presence of another group of bacteria which is capable of respiring carbonate.

In contrast to the sediments of oceans that do not lack oxygen in their deeper waters, the sediment of the Black Sea is very rich in certain organic materials. Some of them are most probably products of fermentation, still another form of microbial life without free oxygen.

Complete Cycle

The transformation of sulfur, that is so important for the maintenance of life in the anoxic water of the Black Sea, might even turn into a complete cycle. This happens directly in the interface where sulfide comes into contact with oxygen-containing surface water. Here we found sizable populations of aerobic bacteria that take the necessary energy for growth from the oxidation of sulfide. They produce sulfur that might settle down to the sediments in tiny particles, or it might be further oxidized to sulfate. The presence of these organisms has never been shown before in large quantities.

A puzzle is, why these bacteria could also be found in the deep anoxic waters. If they are representatives of the known sulfide-oxidizing type, they are not expected to survive for long in this hostile environment. But, isolated and studied in pure cultures, they do not exactly fit that well known type, and we may have found a new metabolic form of marine bacteria. It is not too uncommon in microbiology that an unknown type of organism predicted by mere speculation, was later found to exist. The extreme conditions of the Black Sea present a particular "environmental stress" that may have produced still more strange and highly interesting forms of life.

One of the microbiologist's views of the Black Sea therefore, is not far from that of the "exo-biologist" who is probing Mars for new and unusual forms of life.

Index Errata

THE Editor began to see volumes and numbers swim before his eyes during the preparation of the index volume. Please note that on page 13 are shown the Contents of Volume XIII and on page 14, the Contents of Volume XIV. Self-sticking corrections were made in most cases; if this was not done and fastidious readers do not wish to mar their copies with their own handwriting, such stickers are available upon request.

About the authors

DR. J. M. HUNT is Chairman of our Chemistry Department. Drs. Manheim and Bukry are with the U.S. Geological Survey, respectively at Woods Hole and at La Jolla, Cal. The other authors are all staff members of the Woods Hole Oceanographic Institution.

New Atlas

TWO of our staff members have prepared an atlas: "The Water Masses of the North Atlantic, A Volumetric Census of Temperature and Salinity", by W. R. Wright and L. V. Worthington. Folio 19, Serial Atlas of the Marine Environment. The American Geophysical Society, 1970. $10.00.

This makes the third atlas in this series prepared at this Institution. The others: Folio 2 by Elizabeth H. Schroeder and Folio 7 by D. F. Bumpus and L. M. Lauzier were discussed in Oceanus (see Index). We understand that these folios are considered "best sellers".

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